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AVIONICS-ENABLED OPERATIONS IMPROVEMENTS STUDY

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INTRODUCTION

This document, along with the attached data package, describes the results of the Avionics Enabled Operations Improvements Study, which is Technical Directive 009 of the Infrastructure Study contract (NAS-37588). The Infrastructure Study contract is being worked by General Dynamics and was awarded by NASA Marshall Space Flight Center. Technical Directive 009 was funded by NASA Johnson Space Center, with Don Brown as the contact. The period of performance was 4 March 1991 to 30 August 1991.

The goal of the study was to show that avionics technology can support improvements in system operations across the space exploration infrastructure. Since this is an extremely broad field, a selected set of operations were characterized in terms of avionics impacts. Each characterization selected specific avionics technologies as examples of potential enablers of improvements. The result is a relatively detailed discussion of how a subset of avionics technologies can be applied across a representative set of operations and vehicles.

In this document, numbers in brackets (i.e. [n]) in a sentence refer to the data package page number referenced in that sentence.

SUMMARY & CONCLUSIONS

The Avionics-Enabled Operations Improvements Study has developed a top level and second level characterization of space exploration initiative operations. This is the "Identify Operations" box in the roadmap (Figure 1) shown below. This characterization was focussed on defining operations which have significant avionics involvement, directly or indirectly. For purposes of this study, an extended definition of avionics was used which includes electronic systems used as ground support or mission support equipment. This was done since many of the support systems, now considered to be external to the vehicle, will be carried on-board some extended duration vehicles or systems in the future.

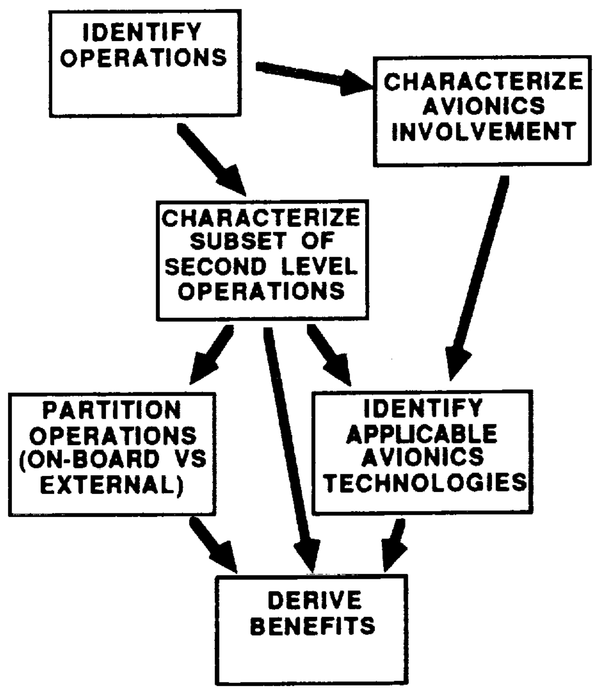

Figure 1: Study Roadmap

Thirteen of the fifty three second level operations were further characterized to develop specific technology issues. Thirteen specific technologies, one for each of the second level operations, were discussed as applicable avionics contributions to improving operations. A discussion of the benefits of each of these technologies was also developed, with an emphasis on cost, schedule, and performance improvements for the system as a result of implementing each technology.

As shown on the chart "Avionics Technology Applicability" [3], all of the technologies discussed have broad applicability across the set of seven SEI infrastructure vehicles selected as representative of the overall infrastructure.

This subset of all the potential avionics technologies which could be applied includes some of the higher payoff or more realizable options.

These results illustrate the importance of the avionics architecture and implementation to SEI operations. Many of the operations which occur today for launch systems are based on extensive ground support equipment. When related operations are performed in the space environment, avionics and automation technology in general becomes much more critical.

RECOMMENDATIONS

The operations characterization and technology identifications done in this study are relatively top level and should be carried further to obtain more qualitative results. In addition, many of the operations and technologies mentioned were not discussed any further. Many of these may have high-payoff avionics opportunities as well and should also be better characterized in those terms.

The technologies discussed here are examples of what should be incorporated into NASA's strategic plan for technology development. Tracking of technology development progress to enable operations improvements should be coordinated across contractors and NASA centers. An effort should be made to focus on SEI operations which cannot be performed without increased levels of automation. Increasing interaction of operations and avionics technologies requires a cooperative development environment to efficiently meet the technical requirements of both disciplines.

From a programmatic perspective, the wide applicability of avionics technology across the infrastructure can be a significant benefit across all programs. Cooperation and communication among those programs to develop and implement these improvements are essential.

OVERVIEW

This study was a follow-on to the Space Avionics Requirements Study (SARS), completed by GDSS in October 1990. One of the top level requirements identified in the SARS task was for reduced system-level life cycle cost through improved operations and logistics. The potential savings through operations improvements are significant. Operations in general account for the largest part of launch costs for Shuttle or expendable launch vehicles. These recurring costs result, in large part, from the labor intensive nature of the operations. Avionics, particularly in the extended sense which includes ground support equipment, can contribute greatly to automating many operations and reducing or eliminating human labor.

This study is intended provide a survey of the operations performed in support of the vehicles and missions that make up a Lunar/Mars exploration effort. This survey consists of top level operations identification and characterization for a subset of the 27 vehicles/systems outlined in the SARS task [6]. Seven of the SARS systems were selected as being representative of the range of operations requirements. These were Space Transportation System (STS), Heavy Lift Launch Vehicle (HLLV), Mars Transfer Vehicle (MTV), Assured Crew Return Vehicle (ACRV), Orbital Maneuvering Vehicle (OMV), Robotic Rover (RR), and Lunar Command and Control Center (CCC). The names of these systems are intended more to convey the mission of the system rather than refer to specific programs (some of which no longer exist in their original form).

A list of operations was developed, ranging from design, development, test & evaluation (DDT&E) and production to range safety and disposal. These extremes were dropped from the list, since avionics impacts were perceived to be minimal, leaving a list of top level operations ranging from processing to refurbishment & maintenance [6]. The judgement that DDT&E and production are not affected by the avionics architecture does not address all aspects of the issue. For instance, the selection of an avionics architecture based on standard common modules may leverage existing designs and production capability. This would significantly reduce design and production cost, thus indirectly improving those operations. For purposes of this study, more direct impacts of avionics on operations are considered.

The top level list of operations was further broken down into more detailed operations. This second level of operations was correlated with the seven selected vehicles. This resulted in a set of tables [7-14], one for each top-level operation, illustrating the applicability of second level operations to each vehicle/system.

Another aspect of operations which involves avionics is the general area of support equipment. This equipment, which for launch vehicles consists of ground support and checkout systems, is considered as part of the extended definition of avionics within this study. This is partly because, while the equipment is usually external to a launch vehicle, for some Lunar/Mars systems such as a MTV or Command & Control Center the equipment will be on-board, and thus a part of the "avionics" system. This partitioning of on-board and external equipment is illustrated by a set of tables [16-18] which show the likely location of responsibility for various second level operations.

Each of the second level operations were characterized in terms of relative avionics involvement and automation potential [21-26]. From this characterization, a set of thirteen operations was selected, using selection criteria based primarily on avionics involvement, automation potential, and availability of relevant data. The last criterion is imposed by the realization that detailed research into new technologies was beyond the scope of this study. Thus, the technologies selected are representative of relatively mature technologies which can be applied now or in the near future. In some cases, the selections also resulted in more quantitative assessments of improvements.

For each of the selected second level operations, a list of system components, functions to be performed, and desired characteristics of the operation was developed. Another level of detail was generated by identifying sub-operations which could be automated. Final characterization consisted of identifying the technologies required to enable automation of the operation [27-93].

Documenting the improvements that avionics can provide began with a characterization of the current method of performing the operation. Descriptions were developed for each of the thirteen selected operations, illustrating some of the processes involved along with some of the drawbacks of the current method. A description of an avionics-improved method of performing the operation was also developed. These two methods were then contrasted to generate a list of operations improvements due to enhanced avionics capabilities [27-93].

In summary, this study has developed a top level characterization of Lunar/Mars infrastructure operations, selected a subset of those operations for further characterization, and identified specific examples of avionics technologies which can significantly improve those operations. Each of the steps in the study is discussed in more detail in the following sections. Tables, charts, and illustrations referred to below are attached following the last section (starting with page 2 of the data package).

OPERATIONS IDENTIFICATION AND CHARACTERIZATION

The Operations Summary table [6] summarizes the applicability of each of the fourteen top-level operations to each of the 27 systems (vehicles or habitats) outlined in the SARS task. Note that the systems are grouped in categories ranging from Earth To Orbit to Surface (Fixed). Seven of these systems (STS, HLLV, MTV, ACRV, OMV, Robotic Rover, and Command/Control Center) were selected for more detailed study. These were considered to be representative of the range of operations which may be required, and also of the set of three mission types identified by Boeing in Space Avionics Architecture Definition Study (NAS1-18762-10). The Boeing mission types (Earth To Orbit, Transfer/Excursion, and Orbital/Surface) group some of the SARS systems together into broader categories which have similar mission requirements.

Four of the top level operations were considered to be minimally affected by avionics technologies. These are DDT&E, Production, Range Safety, and Disposal. The first two of these can be affected significantly, however, by avionics architecture characteristics, particularly open architecture concepts, incorporation of standardization, and commonality of components across systems and subsystems. While these aspects of avionics architecture can have very significant cost impacts to the system design process as well as the procurement and integration of components, the specific technologies used within the architectures will not have as large an impact.

For the bulk of this study, emphasis was placed on ten of the top-level operations: Processing, Final Checkout, Training/Simulation, Mission Preparation, Initiation (Start-Up), Mission Support (Flight Ops), Emergency Procedures, Completion (Shut-Down), Recovery , and Refurbishment / Maintenance. Note that, at the top level, the only discriminator between any of the systems, in terms of operations, is the need for either range safety for launch vehicles or recovery / refurbishment operations reusable systems.

The definitions of the top level operations are relatively self-evident from the lists of second-level operations which follow the summary chart. However, some discussion is appropriate to clarify assumptions.

1 - PROCESSING [7]: This is assumed to include all activities after fabrication of system components up to and including deployment at the site. An example of Segment Assembly And Checkout is assembly of the STS Solid Rocket Boosters. System Integration would refer to operations such as mating of the STS orbiter, external Tank, and SRB's. Transportation and Deployment operations may take a variety of forms. For the STS, this would include moving the vehicle from the Vertical Assembly Building to the pad. For an OMV, this may be as simple as unlatching the vehicle from the Shuttle or Space Station and positioning it with the Remote Manipulator System (RMS).

2 - FINAL CHECKOUT [8]: This is primarily verification a of all vehicle subsystems. It assures the system operator that the post-transportation

condition of the vehicle is acceptable and there are no anomalies. This implies maintenance actions if any defects are identified.

3 - TRAINING / SIMULATION [9]: This operation is intended to include primarily training and verification simulations. Mission planning simulations are including under the Mission Preparation top level operation. It is important to note that these functions can occur before or during actual mission execution, depending on the system. For example, a Mars Transfer Vehicle must have some training and simulation capability to ensure that the crew maintains their expertise throughout a long-duration mission.

4 - MISSION PREPARATION [10]: This operation spans a broad range of time, culminating in a great deal of activity immediately before mission execution. Mission planning may be performed well in advance of the mission, with details modified up to the last few moments, while other activities are focussed on the final steps prior to the mission. Mission preparation ends, for purposes of this study, when a commitment to startup is made (i.e. engine ignition for a launch vehicle).

5 - INITIATION / STARTUP [11]: This operation can occur in a very short time. For purposes of this study, it is defined as the time between (and including) engine ignition and separation from the launch facility. For rovers, engine ignition could be interpreted as application of power to the motors. For habitats, this is essentially the powering-up of the facility.

6 - MISSION SUPPORT (FLIGHT OPS) [12]: This operation encompasses all nominal operations between startup and mission completion, which is defined below.

7 - EMERGENCY PROCEDURES[13]: These operations were broken out because of their unique nature. In most cases there are time constraints imposed on the operations. These operations are expected to take precedence over any other operation being performed, which requires graceful termination of the other operations.

8 - MISSION COMPLETION (SHUTDOWN) [13]: These are operations performed immediately after a vehicle comes to rest (relative to the recovery facility) and prior to physical entry into any part of the vehicle. For habitats, this may be as simple as "shutting off the lights and appliances".

9 - RECOVERY [14]: This is assumed to include all activities required to secure and safe the vehicle/system and remove any crew or payload. This operation is complete when the vehicle is ready to be prepared for its next mission.

10 - REFURBISHMENT / MAINTENANCE [14]: These are all activities required to transition a vehicle form the recovery mode after a mission to a state where it is functionally equivalent to a vehicle coming off the production line.

Some of the second level operations appear under more than one top level operation, particularly health management and system monitoring. These operations are performed on an on-going basis, though possibly with a different focus during different mission modes.

More detailed definitions of some of the second level operations can be found in the avionics operations capabilities charts [20-26] and the charts discussing second level operations and avionics technologies [27-93].

The second level operations listings are correlated with the seven selected infrastructure vehicles/systems. Note that at this level there are more descriminators for operations applicability between systems. The primary reasons for the descriminators are reusability, mission location (surface vs flight), and manned capability.

OPERATIONS PARTITIONING

For today's expendable launch vehicles and the STS, partitioning of operations responsibility into on-board or external is relatively easy since very little operations capability is required on-board. However, for more autonomous systems and those with long duration missions or far-distant missions, on-board operations become more important. One of the goals of this exercise is to characterize operations in terms of their primary controlling location. This can drive operations support equipment designs, since the requirement to perform an operation on the ground could result in an essentially immobile design, whereas an on-board design must be much more efficient in size and weight. A further requirement to use the same equipment either on-board or external may affect overall cost since lower size and weight generally means higher cost. This higher cost for packaging, though, may be offset by reduced development cost resulting from using a single design for multiple applications.

The three charts titled "OPERATIONS RESPONSIBILITY - Responsibility For Operations (On-Board vs External)" [16-18] illustrate the partitioning of the second level operations across the seven selected vehicles/systems.

For some of the operations listed, such as health management, responsibility may be shared by on-board and external systems due to the various aspects of the operation which may be involved. Several operations are on-board only due to time / safety critical requirements, notably engine ignition / stabilization, on-board fire detection / suppression, and backup power activation. Some other operations are external-only, aside from the command and control center mission, including emergency procedures evaluation, mission control interface testing, and system recertification.

Most of the expendable and / or unmanned systems are heavily dependant on external operations. This is partly due to the expense of incorporating equipment into a vehicle which will be thrown away, is not configured for all the necessary equipment, or simply doesn't need the safety or time-critical benefits arising from on-board operations support.

Two significant exceptions are evident, though. The Mars Transfer Vehicle has a long-duration mission in an environment which, partly due to its distance from Earth, is not conducive to tightly coupled external operations support. In addition, in emergency situations such as loss of communication with Earth systems, on-board systems must at least be capable of maintaining the system until communications are restored. The MTV also has responsibility for ensuring that an attached Mars lander is operational. This means the MTV must perform some of the same operations, at the end of its trip to Mars, that would normally be performed by ground support equipment prior to a launch. These operations include verification of all subsystems, crew training, payload checkout, and system securing / safing.

The Command and Control Center, either Lunar or Mars versions, must perform, over the duration of its mission, most of the operations typically performed by ground support personnel, launch control, or mission control functions on Earth. These requirements imply a need to host some responsibility for all operations "on-board" this system.

While the partitioning of operations done here is only for the seven selected systems, these systems are representative of the infrastructure. Some differences may arise for some systems, but the logic behind this partitioning can be applied to any of the systems.

The need to host operations both external and on-board, depending on the system considered, indicates a need to develop generic, modular support equipment scaled to fit either application. In keeping with the on-board avionics goal of limiting the variety of hardware and taking advantage of hardware reusability, the support equipment should be composed, wherever possible, of the same types of hardware used in the on-board systems. Since support equipment and on-board avionics share the characteristic functions of data collection, processing, and communication, this approach appears very feasible.

AVIONICS OPERATIONS CAPABILITIES

The largest part of this study addressed the operations capabilities of avionics systems. Rather than touch on as many aspects of avionics as possible and not provide detail, this study selected a few operations, characterized them in terms of avionics components and functions, identified some desired characteristics, and pointed out some of the avionics technologies which could help achieve those desires.

The first step in documenting avionics capabilities for operations was to characterize avionics involvement for each of the second level operations. As shown on the Definitions Of Ratings chart [20], this involvement was defined as the degree to which electronic systems carry out operations functions. For purposes of this study, the electronic systems included in avionics incorporated on-board or potentially on-board electronics. This refers to the need to carry, on board some long-duration missions such as a MTV or CCC would encounter, many of the electronic systems often associated with ground support equipment. As an example, communications system diagnostic equipment would be considered external for a launch vehicle, but would be required "on-board" an extended duration Lunar or Mars command and control center.

Avionics involvement was rated as high, medium, or low, based on whether the avionics system was the primary system involved in the operation, had significant involvement but shared responsibility with other systems, or had only a supporting role in carrying out the operation.

In addition to the avionics involvement, an assessment was made on the automation potential of the operation due to the avionics. These ratings also were of the form high, medium, or low, depending on whether the operation could be fully automated, would require some manual interaction, or would require a significant amount of manual input.

The six charts titled "AVIONICS CHARACTERIZATION - Operations Suitable For Avionics Automation" [21-26] list the second level operations along with the avionics involvement and automation potential ratings. A very brief explanation follows each of the ratings. A check mark to the left of an operation indicates that it was selected for more detailed inspection. The operations selected, along with the corresponding top level operation, are listed below:

Second Level Operation	Top Level Operation
• Health Management	Processing (Among Others)
• Avionics Verification	Final Checkout
• Fluids System Verification	Final Checkout
• Mission Simulation	Training / Simulation
• Crew Training	Training / Simulation
• Mission Planning	Mission Preparation
• System Monitoring	Mission Support (Among Others)
• Rendezvous	Mission Support (Flight Ops)
• Docking	Mission Support (Flight Ops)
• Mission Abort	Emergency Procedures
• System Safing	Recovery
• System Inspection	Refurbishment / Maintenance
• Subsystem Inspections	Refurbishment / Maintenance

Each of these second level operations was characterized further to identify avionics technologies required and to indicate potential methods of improving the operation through avionics improvements. Savings were identified by selecting one of the avionics technologies from each of the second level operations and illustrating how its application improves the operation. The characterization of each of these operations in terms of avionics is discussed in the following paragraphs, along with an example of potential improvements. The referenced charts can be found under

HEALTH MANAGEMENT

Health management, as defined for this study, is the active part of an Integrated Health Management (IHM) architecture. Where IHM incorporates data acquisition, system monitoring, and management of resources [28], the health management operation defined here is limited to the latter. However, significant overlap still exists since data acquisition and system monitoring also require resource management.

Health management operations consist of control of system resources, primarily redundant resources or those required to carry out Integrated Health Management functions [27a]. Functions which can be automated for health management include functional verification of instrumentation, data acquisition control, subsystem fault analysis, subsystem reconfiguration, and data storage [29]. Avionics technical requirements to support this automation include smart instrumentation, data acquisition / formatting, data processing and storage devices, application processing (software), and data networks [30].

The specific avionics technology selected as an example of avionics improvements to the health management operation is sensor correlation / fusion. Synthesis of sensor data to allow insight into system operation is currently done primarily by external systems and tends to require large teams of humans as engineers and analysts [31]. This "standing army" is necessary to ensure that all systems are monitored and that any possible anomaly will be identified and characterized. This is not limited to direct flight support, since much of this activity occurs before or after a launch vehicle mission. Further complicating the issue, individual sensors are used for each measurement, with duplication of sensors required where reliability is critical. Since instrumentation (sensor) failures are a very large percentage of system anomalies, the result is a relatively fragile system with little of the robustness necessary for cost effective operation.

Automated sensor correlation and fusion, particularly when incorporated into an on-board Vehicle Health Management system, can significantly reduce the extent of health management operations [32]. Correlation and fusion of sensor data allows for functional redundancy, where combined data from a number or sensors (even from a variety of types of sensors) can be used to determine additional measurement values. This can be used to reduce the number of sensors, to identify a failed sensor, and to allow continued mission operations by working around a failed sensor. Automation of this process using expert systems allows much faster processing and again reduces the workload.

Using GDSS Data Analyst Intelligent System (DAIS) for Atlas/Centaur launches as an example, a 20% reduction in post-flight data analysis manhours has already been realized. Other advantages which have not been quantified, but could be realized in a fully implemented application, include reduced instrumentation hardware, fewer delays due to sensor faults, and improved support for real time fault detection, isolation and recovery [33].

AVIONICS VERIFICATION

During final checkout, just after the production process, each component of the avionics system is checked to ensure that it works as specified. While the high level goal is system level testing, the process involves checks of all levels, from individual electronic components to modules and subsystems [34]. All interfaces are checked to ensure continuity and proper configuration. Checks on computer memory devices and contents ensure that the proper data has been loaded and is secure. A fully automated verification process which can make results available to any on-board or external node that requires it is desirable.

Most avionics verification functions can be fully automated, including built-in-test (BIT) at all levels, memory error detection, and sensor identification [35]. Subsystem simulation can allow automated verification of systems which may require outside stimulus which are not available during the process. Hardware identification through electronic nameplates can ensure that the system configuration matches the required configuration. Technology now being developed to provide "smart connectors" can help automate the verification of both electrical continuity and system configuration.

Technical requirements to automate these functions include smart sensors and effectors, high levels of BIT to improve testability, a test bus architecture to distribute test data and control the process, algorithms to perform fault trend analysis, and miniaturization of components [36].

Built-In-Test technology, as an example of an avionics verification improvement enabler, is used only at limited levels today [37]. Smart instrumentation, capable of reporting sensor faults, has not been fielded extensively to date. Disconnection of components to check continuity results in a reverification process for the connection when it is reconnected, all of which is time and labor intensive.

Use of enhanced BIT, fully integrated throughout all levels of the system, can provide a virtually fully automated checkout process [38]. In conjunction with external control and stimulus, the BIT process can exercise nearly all components. Both off-line and on-line BIT can be employed, allowing the process to support system monitoring functions as well.

BIT technology can contribute significantly to automation of the checkout process, and, particularly when applied to sensors, can reduce delays due to analysis of anomalies [38].

FLUIDS SYSTEM VERIFICATION

Analogous to avionics system verification, fluids system verification involves checks of all fluids system components including valves, tanks, and plumbing [39]. Checks include leak tests, valve operation tests, flow tests, and fluid condition checks. Ideally these would be accomplished with no breaking of connections and would be performed at operational environmental conditions, particularly temperature and pressure.

All of the checks identified can be automated functions using appropriate technologies [40]. Spectral analysis, expert systems, fiber-optic fluid detectors, laser reflectance fluid detectors, flow meters, pressure sensors, current sensors, and temperature sensors can all be applied to automation of fluids system checkout. In addition, electromechanical actuators, in place of hydraulic actuator systems, can eliminate the need to verify hydraulic systems entirely. This checkout operation would be replaced with a much simpler built-in-test process for the electromechanical implementation.

Current methods are repetitive and labor intensive, and require technically trained personnel [42]. In addition, current procedures are seriously inadequate for space based operations, and do not readily support high launch frequencies and parallel launch or mission operations.

As an example of a technology that can be readily applied, current signature analysis for solenoid valve testing can automate a process that is currently labor intensive [43]. It can eliminate manual tests including those that simply feel or or listen for valve operation. This reduces checkout time and eliminates breaking fluid lines and retesting for leaks. In addition, the technology lends itself readily to in-space processing and does not require extensive instrumentation to mount on the vehicle. Analysis of results can be automated as well, thus eliminating the need for highly trained personnel at the checkout site [44].

MISSION SIMULATION / CREW TRAINING

Because of the similarity and interrelationship between mission simulation and crew training, they have been combined for discussion here and in the attached charts [45]. The mission simulation operation alone is applied to a variety of system modes. Individual simulation modes include flight, docking, landing, manipulator operation, and emergency procedures simulation. In short, any of the launch or mission operations can be targets for simulation. Many reasons exist for performing these simulations, including trajectory verification, human factors engineering, flight dynamics analysis, and verification of procedures. Of particular interest, though, is the use of simulation for crew training.

Crew training involves a number of approaches, but repetition of procedures in a realistic environment that exercises a variety of potentially necessary skills is invaluable. This training traditionally requires simulators with multi-degree of freedom motion, high resolution projection displays, realistic human interfaces, etc. While this is practical, though expensive, on the ground, fielding such a system on a long-duration Mars transfer mission or habitat is not as simple. What is desired for these missions is a simulation capability with minimal hardware and software beyond what is required for normal system operation.

Simulator operations are essentially automated today on the ground [48]. However, the modelling tools and simulation tools are not fully integrated and streamlined. Common databases and automated design and coding are not mature. On-board modelling and simulation capability is not supported by avionics architectures.

The technologies required for simulation and automation of simulation control continue to evolve [49]. Modelling techniques, computer processing capability, and computer graphics capability increase continually. Integrated design, development, and simulation environments will be a requirement for improved operations. For crew training aspects, technology advances in simulated displays, control interfaces, and sensory feedback will be required. Making such systems compact enough to fit within a long-duration vehicle is a significant challenge. One alternative is to take advantage of on-board avionics systems by using them in simulation mode, but challenges then arise in how to isolate the simulation portion from the system control portion.

For modelling and simulation in general, advanced tools are estimated to reduce model generation time by an order of magnitude [50]. Integrated total system simulations will improve design confidence and provide an improved environment for testing individual components, whether real or simulated. Advanced capabilities will also be required to enable cost effective on-board simulation capability for crew training.

MISSION PLANNING

Mission planning operations occur throughout preparation phases for a mission, in parallel with other operations [51]. While this is primarily an operation which is external to the vehicle, avionics related equipment is involved, particularly during mission simulations. For some facilities such as Space Station, a Mars Transfer Vehicle, and Lunar and Mars command and control centers, mission planning functions may be supported on-board. The necessary components are processing, memory, data storage, and data networking systems.

Desired characteristics of an advanced mission planning capability include automated generation of flight software, service requests, flight and launch plans, and schedules. Standardized flight profiles and support services will simplify the task. Automated logistics planning and tracking will help streamline other operations.

Technology requirements for automation of mission planning include computer aided software engineering (CASE) tools, paperless management systems, mission simulation capability, expert systems, automated communication scheduling, health monitoring, and increased processing capabilities to support all of the above as well as adaptive GN&C concepts [53].

Taking flight design and integration as a specific mission planning example, current methods are time consuming, costly processes [54]. Millions of dollars are spent to support each vehicle's mission. Atlas/Centaur mission planning, for example, originally took 1-2 years and required 20-30 thousand man hours of labor. Each mission planned was unique, with little legacy for later missions. Software maintenance alone consumed 60-80% of the total man hours.

An improved method of accomplishing mission planning takes advantage of common databases and an integrated environment to provide a more efficient mission design process [55]. CASE tools are employed to help generate requirements, a common database is queried to extract applicable models and designs, simulations are performed, using the same human interface, to validate the design, and automatic code generation is used for actual flight software. Integration of the final code with flight or testbed hardware then allows hardware in the loop verification of the design.

An order of magnitude reduction of flight design and integration cost is estimated by using this type of design/development environment [57]. The Mission Design System for GDSS launch vehicles is expected to reduce mission planning from years to months. In addition, early system testing using models and simulations increases confidence in hardware and software designs and reduces verification and validation costs by eliminating problems early. This type of streamlined environment is required for efficient space-based mission planning operations.

SYSTEM MONITORING

While system monitoring, like health management, is an on-going process, its function during mission support (flight operations) is critical. This operation is responsible for informing flight and ground personnel of system status and making critical information available for the use of on-board and ground systems [58]. Desired characteristics include automated real-time data acquisition and distribution, and the use of standard workstations for data display and manipulation.

Data display, storage, and distribution functions can be automated [59]. Health monitoring, a primary concern of the system monitoring operation, collects input data and uses it, along with a historical database and command data, to perform fault detection, fault prediction, trend analysis, sensor fusion, database heuristics, fault logging, and generation of documentation. One of the principal results of this process is an alert to the crew, mission support personnel, and/or health management systems whenever an anomaly occurs [60].

Avionics technology required to perform system monitoring includes data acquisition and formatting hardware and software, data processing systems, data storage and display devices, and data distribution systems [61].

Using data acquisition hardware as an example, current methods are application specific [62]. Dedicated input lines are used for each measurement, with dedicated circuitry to perform excitation, sampling, and formatting. Separate data acquisition systems are used for flight control measurements and telemetry measurements. Limited BIT and data distribution capability means very limited support for automated checkout.

The use of standardized data acquisition modules is a significant improvement over current methods [63]. Modules are identical in design, with one design for analog interfaces and another for digital. Each channel of each module can be programmed to accommodate a variety of sensor types. In addition, programmable gains and offsets allow sensors to be tested in ambient conditions as if they were in operational conditions, a significant advantage if cryogenic operation is required. It is estimated that 95% of existing launch vehicle measurement types can be accommodated with this approach. An additional advantage to the microprocessor-based interface module approach is that it can now support a wide range of data filtering and formatting functions. These include data compression, linearization, and engineering units conversion.

In addition to lower DDT&E costs due to the standardized module approach, this concept reduces vehicle instrumentation requirements since the hardware can be programmed for various sensors [64]. Since the interface modules are designed to tie into system data buses, sensor data can now be made available across a single data path to both flight control and telemetry / health monitoring systems. Finally, microprocessor based modules and programmable sensor interfaces support BIT and automated checkout processes.

RENDEZVOUS AND DOCKING

The rendezvous and docking operations, because of similar requirements, can be discussed together [65]. From an avionics perspective, the primary differences are in the sensors required to determine position and orientation. Rendezvous operations typically require relatively high accuracy inertial navigation systems aided with periodic updates from other systems such as the global positioning system (GPS). Docking operations supplement the navigation sensors with higher precision components such as optical / infrared imaging systems and radar and laser ranging systems.

In addition to maneuvering to the proximity and then docking with the target, other functions must be considered for an autonomous rendezvous and docking operation [66]. Collision avoidance and debris deconfliction must be accommodated. Contamination of the space around the target must be avoided. While a fully autonomous system may be the goal, other modes of operation must be considered, including supervised automatic, teleoperation, and use of the avionics system to monitor manual rendezvous and docking operations.

Technology requirements to accomplish these goals include integrated INS/GPS systems, imaging and image processing equipment, alignment systems, radar / ladar systems, communication systems, and high resolution tracking systems [67].

Traditional methods are characterized by use of separate systems for the various rendezvous and docking phases [68]. Fully autonomous docking is somewhat risky, since range resolutions of around 1.5 meters and range rate accuracies of 0.3m/s are typical during the final docking phase.

As an example of avionics improvements, a digital imaging system, including image processing hardware and software, can obtain docking port imagery, extract range and orientation cues, and determine relative position and attitude [69]. These data can be used to control the final stages of docking with high precision. Using this technology, range resolutions of 1.0% of range and 0.005 meters during the final docking phase are possible. Range rate accuracy of 0.3% of range and 0.003 m/s are also possible. This technology also directly supports operation in the various modes mentioned above, thus reducing the need for discrete systems for each mode [70].

MISSION ABORT

Mission abort operations, under the emergency procedures top-level operation, include any emergency abort procedures carried out during the mission [71]. For launch vehicles, this is mostly during the boost phase. For orbital systems this would include emergency evacuation and initiation of return to a safe location, possibly a return to Earth. For surface systems, this can be as simple as shutting down power to the rover or habitat and moving to a safe haven.

Regardless of the type of system, some basic avionics related functions must be performed. For high energy vehicles (i.e. launch or transfer vehicles) mission replanning and emergency systems activation may precede separation of the crew compartment or controlled return of all or part of the vehicle in a degraded state. For other systems, real-time mission replanning may not be necessary, though activation of backup systems may take a higher priority.

Generally, ensured human safety is required. Robust mission replanning can help provide safe abort options. Reliable assessment of vehicle and external conditions, along with reliable activation of emergency and backup systems, is required.

Functions that can be automated for mission aborts include fault and damage assessment, course / trajectory selection and planning, selection of return site / safe haven, abort mode guidance, navigation and control, and emergency or backup system activation [72].

Technical requirements to automate these functions include health monitoring / management, artificial intelligence, sensor data acquisition, position and attitude determination, and real-time adaptive guidance, navigation and control [73].

Currently, particularly for launch vehicles, preplanned contingency operations are required to accommodate abort operations [74]. Significant logistics problems must be overcome to provide abort options for STS missions, including tracking, communications, and emergency landing equipment at sites around the Earth. Conditions must be nominal at all locations or a launch delay is required. Emergency abort from Space Station would require activation of an emergency return vehicle and return to Earth.

As a specific technology example, adaptive guidance, navigation and control (AGN&C) provides many benefits [75]. An adaptive optimal thrust resolver compensates for engine failures or off-nominal thrust variations. Command multiplier steering supports mission operations under engine-out conditions. In addition, various techniques such as fuel slosh estimators, winds aloft prediction via laser radar, and dynamic inversion control all help maintain vehicle performance under unanticipated conditions.

Application of AGN&C technology can have immediate savings due to the ability to launch a vehicle under more dynamic environmental conditions than current weather prediction techniques allow, thus reducing launch delays due to abort location weather conditions [76]. Enhanced engine-out capability can expand the operational envelope for launch vehicles beyond that which, when exceeded, now calls for a mission abort. Some of the AGN&C technologies can be applied to orbital or transfer systems, such as fuel slosh estimators, adaptive bending filters, and engine out support techniques.

SYSTEM SAFING

In the top-level operation referred to as recovery, system safing operations are intended to ensure that a returnable and/or reusable system can be shut-down and placed in a condition which is safe for the flight and ground crew [77]. It is also necessary to ensure that no damage can result from on-board systems, either to the vehicle itself or to external equipment. Considering the volatile and high energy fluids, gasses, and electrical systems aboard most vehicles, this is a significant operation. Most of these operations are applicable, in addition to vehicles returning from missions, to vehicles undergoing deactivation due to launch delays.

Examples of functions which must be performed include propellant discharge, off-loading of hazardous storables, and safing of pyrotechnic devices. This must all be done reliably and with minimal (preferably zero) environmental impact. In addition, these operations should be performed such that they do not degrade the system and impose additional maintenance or repair operations before the system can be reused.

Functions which can be automated include cryogenic fluid recovery, toxic materials recovery, power system shutdown, propulsion system shutdown, and pyrotechnic isolation [78]. Technical requirements for avionics automation of these operations revolve around sensors, sensor data acquisition, and control of the various valves and relays required to deactivate systems and dispense materials [79].

For pyrotechnic systems, as an example, current systems cannot be completely closed out at off-site processing locations [80]. This requires additional processing, precautions, and personnel at the launch or recovery site as well as at the final processing facility. Limited health monitoring capability exists, and RF initiated systems are susceptible to inadvertent activation through EMI, RFI, and static discharge induced currents.

An avionics related improvement on current methods is the use of laser firing units (LFU) for ordnance initiation [81]. These allow ordnance to be installed and safed without RF silence. They also increase testability and allow autonomous system verification. LFU's are highly reliable since they can be designed with no moving parts and are insensitive to RF, EMI, and light frequencies outside the operational range.

Incorporation of LFU technology improves pyrotechnic system safety while reducing both operations and recurring cost [82]. For HLLV, vehicle hardware cost savings of $100K have been estimated, while lower weight and size improve effective vehicle performance. Operations costs are improved significantly through reduction of launch and recovery site personnel.

SYSTEM / SUBSYSTEM INSPECTION

System and subsystem inspection during the refurbishment / maintenance phase of vehicle / system processing are focussed on assessing the state of the system and identifying maintenance actions which must be performed. Both levels are addressed together since system inspection can be considered the sum of all subsystem inspections. The summing process requires test communication (control and response) as well as processing of the results. Many of the procedures performed here can help eliminate pre-mission processing procedures if properly performed.

Functions which must be performed include downloading of system status information, physical inspection of the system, diagnostic and prognostic activity (including documentation), and maintenance procedure determination and documentation [83]. Ideally, these procedures should be thorough, reliable, and accurate. Automation of diagnostic and prognostic procedures is desirable. Faults should be isolated to the lowest possible maintenance level to help optimize maintenance procedures. Finally, the generation and distribution of documentation should be automated.

At the system level, automated functions include data download, diagnostics, prognostics, maintenance scheduling , and documentation generation and distribution [84]. Technical requirements to accomplish this include artificial intelligence / expert systems, health monitoring, a test bus communications architecture, and data processing and storage capability [85].

Using test and maintenance bus communications as an example of an avionics improvement technology, no current capability exists for gathering all test data via a separate test bus [86]. This means that system inspections must be performed by personnel with high levels of expertise in each subsystem.

The use of a test and maintenance bus, along with health monitoring, sensor , and expert system technologies, allows more thorough inspection of the entire system, regardless of operational mode [86]. Tests can be performed in parallel with other operations since an independent data path is used. In addition, less external test equipment is required since a single, standard test interface is required for all test data [87].

At the subsystem level, taking propulsion system inspection as an example, diagnostics and prognostics can be based, at least partially, on health monitoring data downloaded from an engine health monitoring system [88]. These data can provide insight into engine and engine controller operation during the mission. Correlated with other engine test data and expected values, these data can also be used, via application of expert systems, to generate diagnostic and prognostic results.

Advanced Maintenance Sensors fit into a category of technology improvements for subsystem inspection [91]. Currently, instrumentation sensors are placed for mission success, flight safety, and performance monitoring data gathering. The need to report subsystem condition for maintenance purposes is relatively new.

Advanced propulsion system related sensors which are emerging include capacitive pressure and blade clearance, acoustic emissions, fiber-optic deflectometer, fiber-optic laser vibration, optical pyrometer, and on-board plume and mass spectrometry sensors [92]. Incorporation of such sensors for maintenance applications, along with health monitoring and reporting capability, allows post-flight inspection and maintenance to use in-flight condition and operation as a basis for maintenance actions rather than just post flight data [93].

Automation of inspection operations, in a hierarchical manner across all subsystems, will help reduce turn-around time of reusable systems and improve repeatability of procedures for each vehicle processed. While full automation of all inspection operations is unlikely, application of avionics (including support equipment) as either an enabling technology or an aiding technology will have long term benefits.

ACRONYM LIST

ACRV	Assured Crew Return Vehicle
ACS	Attitude Control System
AGN&C	Adaptive Guidance, Navigation and Control
AI	Artificial Intelligence
BIT	Built In Test
CASE	Computer Aided Software Engineering
CCC	Command Control Center
CRT	Cathode Ray Tube
DAIS	Data Analysts Intelligent System
DDT&E	Design, Development, Test and Evaluation
DOF	Degree of Freedom
ECLSS	Environmental Control Life Support System
EMI	Electromagnetic Interference
EVA	Extra-vehicular Activity
FDIR	Fault Detection, Isolation and Recovery
FMEA	Failure Modes Effects Analysis
GDSS	General Dynamics Space Systems
GHM	Ground Health Management
GN&C	Guidance, Navigation and Control
GPS	Global Positioning System
GSE	Ground Support Equipment
HIL	Hardware In the Loop
HLLV	Heavy Lift Launch Vehicle
HM	Health Management
HVPS	High Voltage Power Supply
IHM	Integrated Health Management
INS	Inertial Navigation System
JIAWG	Joint Integrated Avionics Working Group
LEV	Lunar Excursion Vehicle
LFU	Laser Firing Unit
LRM	Line Replaceable Module
LRU	Line Replaceable Unit
LTV	Lunar Transfer Vehicle
LVDT	Linear Variable Differential Transformer
MDS	Mission Design System
MEV	Mars Excursion Vehicle
MFLOPS	Million Floating-point Operations Per Second
MIPS	Million Instructions Per Second
MTTN	Man Tended Terminal Node
MTV	Mars Transfer Vehicle
NDV	NASP Derived Vehicle
OMV	Orbital Maneuvering Vehicle
PMU	Personal Maneuvering Unit

ACRONYM LIST (cont'd)

R&D	Research & Development
R&D	Rendezvous & Docking
RF	Radio Frequency
RFI	Radio Frequency Interference
RMS	Remote Manipulator System
RR	Robotic Rover
RVDT	Rotational Variable Differential Transformer
SARS	Space Avionics Requirements Study
SEI	Space Exploration Initiative
SRB	Solid Rocket Booster
SSCZ	Space Station Control Zone
SSF	Space Station Freedom
STM	System Test & Maintenance
STS	Space Transportation System
STS-C	Space Transportation System-Cargo
TM	Test & Maintenance
TVC	Thrust Vector Control
VHM	Vehicle Health Management

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DATA PACKAGE

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SUMMARY / CONCLUSIONS

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SUMMARY
Avionics Technology Applicability

AVIONICS TECHNOLOGY	STS	HLLV	MTV	ACRV	OMV	RR	CCC
Automated Sensor Correlation and Fusion	X		X	X	X	X	X
Avionics Built-In-Test	X	X	X	X	X	X	X
Electromechanical Actuators	X	X	X	X	X	X	X
Current Signature Analysis	X	X	X	X	X		X
Modelling / Simulation Tools	X	X	X	X	X	X	X
Common Databases	X	X	X	X	X	X	X
Integrated Development Environment	X	X	X	X	X	X	X
Standardized Data Acquisition Modules	X	X	X	X	X	X	X
Digital Imaging Systems	X		X		X	X	X
Adaptive Guidance, Navigation, and Control	X	X	X	X	X	X	
Laser Firing Units	X	X	X	X	X		
Test & Maintenance Data Bus	X	X	X	X	X	X	X
Advanced Maintenance Sensors	X		X	X	X	X	X

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AVIONICS-ENABLED OPERATIONS IMPROVEMENTS STUDY
Summary / Conclusions

SUMMARY

- FOURTEEN TOP LEVEL OPERATIONS IDENTIFIED
- FIFTY-THREE SECOND LEVEL OPERATIONS IDENTIFIED
- THIRTEEN SECOND-LEVEL OPERATIONS CHARACTERIZED FOR AVIONICS-ENABLED IMPROVEMENTS
- THIRTEEN SPECIFIC TECHNOLOGIES DISCUSSED AS EXAMPLES OF AVIONICS BENEFITS
- OPERATIONS AND TECHNOLOGIES CORRELATED WITH SEVEN SELECTED SEI INFRASTRUCTURE SYSTEMS

CONCLUSIONS

- MOST OPERATIONS ARE SIGNIFICANTLY AFFECTED BY AVIONICS
- AVIONICS TECHNOLOGY IMPROVEMENTS CAN HAVE WIDESPREAD IMPACTS ON OPERATIONS IN GENERAL
- SPECIFIC AVIONICS TECHNOLOGIES FOR OPERATIONS IMPROVEMENTS ARE APPLICABLE ACROSS THE ENTIRE SEI INFRASTRUCTURE
- IMPROVEMENTS WILL BE NECESSARY TO MEET SPACE OPERATIONS REQUIREMENTS

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FINAL REPORT

OPERATIONS IDENTIFICATION AND CHARACTERIZATION

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SPACE INFRASTRUCTURE:

OPERATIONS SUMMARY

OPERATIONS ↓ / SYSTEMS →	EARTH TO ORBIT				TRANSFER / EXCURSION					ORBITAL					SURFACE (MOBILE)					SURFACE (FIXED)							
	STS	STS-C	HLLV	NDV	LTV	MTV	LEV	MEV	ACRV	PMU	OMV	SSF	MTTN	EXPL. PROBE	ROVER (PRESS.)	ROVER (UN-PRESS)	ROVER (ROBOTIC)	SOIL MOVER (M)	SOIL MOVER (UM)	PERSONNEL QTRS	CMD/CNTRL CENTER	POWER PLANT	SOIL PROC. FACILITY	MASS DRIVER	SCIENCE CENTER	SPACEPORT	ENV. OPS CENTER
DDT&E	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
PRODUCTION	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
PROCESSING	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
CHECKOUT	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
TRAINING/SIMULATION	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
MISSION PREPARATION	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
INITIATION (START-UP)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
MISSION SUPPORT (FLIGHT OPS)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
EMERGENCY PROCEDURES	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
COMPLETION (SHUT-DOWN)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
RECOVERY	X	X		X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X
REFURBISHMENT/MAINTENANCE	X	X		X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X
RANGE SAFETY	X	X	X	X																							
DISPOSAL	X	X		X	X	X	X	X	X	X	X	X	X		X	X	X	X	X								
	↑		↑		↑				↑		↑						↑				↑						

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OPERATIONS IDENTIFICATION
Basic Infrastructure Operations

PROCESSING	STS	HLLV	MTV	ACRV	OMV	RR	CCC
Preparation Of Facilities							
– Test / Verify Support Equipment	X	X	X	X	X	X	X
– Check Interfaces	X	X	X	X	X	X	X
Segment Assembly And Checkout	X	X	X	X	X	X	X
System Integration							
– Interface Verification (Prior To Mating)							
- Power / Comm. To Vehicle/Habitat	X	X	X	X	X	X	X
- Vehicle/Habitat To Payload/Environment	X	X	X	X	X	X	X
- Inter-System	X	X	X		X	X	X
– Interface Checkout (After Mating)	X	X	X	X	X		X
Payload Integration							
– System Checkout	X	X	X	X	X		
– Interface Checkout	X	X	X	X	X		
System Monitoring	X	X	X	X	X	X	X
Health Management	X	X	X	X	X	X	X
Ordnance Preparation	X	X	X	X			
Transportation							
– Through Process	X	X	X	X	X	X	
– To Operational Site	X	X		X		X	
Deployment At Site	X	X		X		X	X

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OPERATIONS IDENTIFICATION
Basic Infrastructure Operations

FINAL CHECKOUT	STS	HLLV	MTV	ACRV	OMV	RR	CCC
Avionics Systems Verification	X	X	X	X	X	X	X
Structural Verification	X	X	X	X	X		X
Propulsion Systems Verification	X	X	X	X	X	X	
Fluids System Verification	X	X	X	X	X		
Electrical System Verification	X	X	X	X	X	X	X
Range Safety System Verification	X	X					
ECLSS Verification	X		X	X			X
Ordnance System Verification	X	X	X	X			
System Monitoring	X	X	X	X	X	X	X
Health Management	X	X	X	X	X	X	X

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OPERATIONS IDENTIFICATION
Basic Infrastructure Operations

TRAINING / SIMULATION	STS	HLLV	MTV	ACRV	OMV	RR	CCC
Mission Simulation	X	X	X	X	X	X	X
Simulation Analysis	X	X	X	X	X	X	X
Emergency Procedures Validation	X	X	X	X	X	X	X
Crew Training	X		X	X	X	X	X
Performance Evaluation	X		X	X			X

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OPERATIONS IDENTIFICATION
Basic Infrastructure Operations

MISSION PREPARATION	STS	HLLV	MTV	ACRV	OMV	RR	CCC
Mission Planning							
– Mission Simulation	X	X	X	X	X	X	X
– Mission Software Validation / Coordination	X	X	X	X	X	X	X
– Trajectory / Performance Data Validation	X	X	X	X	X		
– Data / Tracking Coordination	X	X	X	X	X	X	
System Monitoring	X	X	X	X	X	X	X
Health Management	X	X	X	X	X	X	X
Communications	X	X	X	X	X	X	X
Data Loading	X	X	X	X	X	X	X
Interface Verification							
– System Interfaces	X	X	X	X	X	X	X
– Mission Control Interfaces	X	X	X	X	X	X	X
Integrated System Checkout	X	X	X	X	X	X	X
Consumables Loading	X	X	X	X			X
Propellant Loading	X	X	X	X	X	X	
Power System Activation	X	X	X	X	X	X	X

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OPERATIONS IDENTIFICATION
Basic Infrastructure Operations

INITIATION/STARTUP	STS	HLLV	MTV	ACRV	OMV	RR	CCC
System Monitoring	X	X	X	X	X	X	X
Health Management	X	X	X	X	X	X	X
Communication	X	X	X	X	X	X	X
Propulsion System Activation	X	X	X	X	X	X	
Internal Power Activation	X	X	X	X	X	X	X
Engine Ignition / Stabilization	X	X	X	X	X		
Separation	X	X	X	X	X		

OPERATIONS IDENTIFICATION
Basic Infrastructure Operations

MISSION SUPPORT (FLIGHT OPS)	STS	HLLV	MTV	ACRV	OMV	RR	CCC
Data Acquisition							
– Mission / Experiments	X	X	X		X	X	X
– System Telemetry	X	X	X	X	X	X	X
System Monitoring	X	X	X	X	X	X	X
Health Management	X	X	X	X	X	X	X
Communications	X	X	X	X	X	X	X
Payload Checkout	X		X		X		
RMS Operation	X		X		X	X	X
Mission Performance							
– Payload Deployment	X	X	X		X	X	
– Rendezvous	X		X		X	X	
– Payload Retrieval	X		X		X	X	
– Docking	X		X		X		
Tracking							
– Mission Abort (Destruct)	X	X		X			
– Mission Abort (Deactivate)	X		X		X	X	X

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OPERATIONS IDENTIFICATION
Basic Infrastructure Operations

EMERGENCY PROCEDURES	STS	HLLV	MTV	ACRV	OMV	RR	CCC
Reentry Abort	X		X	X			
Landing Abort	X		X	X			
Crew Egress	X		X	X			X
Fire Detection And Suppression	X	X	X	X			X
ECLSS Failure Recovery	X		X	X			X
Backup Power Activation	X	X	X	X	X	X	X
Subsystem Shutdown / Recovery	X	X	X	X	X	X	X

MISSION COMPLETION (SYSTEM SHUTDOWN)	STS	HLLV	MTV	ACRV	OMV	RR	CCC
Subsystem Shutdown	X	X	X	X	X	X	X
Power System Deactivation	X	X	X	X	X	X	X

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OPERATIONS IDENTIFICATION
Basic Infrastructure Operations

RECOVERY	STS	HLLV	MTV	ACRV	OMV	RR	CCC
System Securing	X		X	X	X	X	
System Safing	X		X	X	X	X	
Crew Egress	X		X	X			
Payload Removal	X		X		X	X	
Transportation To Refurbishment / Disposal Site	X		X	X	X	X	

REFURBISHMENT / MAINTENANCE	STS	HLLV	MTV	ACRV	OMV	RR	CCC
Decontamination / Cleaning	X		X	X	X	X	X
System Inspection	X		X	X	X	X	X
Subsystem Inspection	X		X	X	X	X	X
Subsystem Repair	X		X	X	X	X	X
Subsystem Changeout	X		X	X	X	X	X
System Recertification	X		X	X	X	X	X

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OPERATIONS PARTITIONING

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OPERATIONS PARTITIONING
Responsibility For Operations (On-Board vs External)

OPERATION	STS	HLLV	MTV	ACRV	OMV	RR	CCC	COMMENTS
Health Management	O,E	O,E	O,E	O,E	O,E	O,E	O,E	Mission Phase Dependent
System Monitoring	O,E	O,E	O,E	E	E	O,E	O	Analysis Of System Status
Data Acquisition	O,E	O,E	O,E	E	E	O,E	O	Status Collection/Distribution
Integration Checkout	E	E	O,E	E	E	E	O	Final Assembly Check
Avionics Verification	E	O,E	O,E	E	E	E	O	Final System-Level Check
Propulsion Sys. Verification	E	E	O,E	E	E	E	–	Final System-Level Check
Fluids Sys. Verification	E	E	O,E	E	E	E	O	Final System-Level Check
Electrical Sys. Verification	E	E	O,E	E	E	E	O	Final System-Level Check
ECLSS Verification	E	–	O,E	E	–	–	O	Final System-Level Check
Ordnance Sys. Verification	E	E	O,E	E	E	E	O	Final System-Level Check
Mission Simulation	E	E	O,E	E	E	E	O	Planning/Training Simulation
Simulation Analysis	E	E	O,E	E	E	E	O	Results Of Simulation
Emerg. Proc. Evaluation	E	E	E	E	E	E	O	Contingency Planning Analysis
Crew Training	E	–	O,E	E	E	E	O	Flight Crew Only
Crew Performance Eval.	E	–	O,E	E	E	E	O	Training/Sim Results Analysis
Mission Planning	E	E	O,E	E	E	E	O	
Payload Integration	E	E	O	–	O,E	E	O	Physical/Electrical Connections
External Interface Verification	E	E	O,E	E	E	E	O	Basic Connectivity Checks
Communications	E	E	O,E	O	E	E	O	Upload/Download/Landline
Data Loading	E	E	O,E	O,E	E	E	O,E	Launch/Mission Data

O = On-Board, E = External

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OPERATIONS PARTITIONING
Responsibility For Operations (On-Board vs External)

OPERATION	STS	HLLV	MTV	ACRV	OMV	RR	CCC	COMMENTS
Mission Control I/F Testing	E	E	E	E	E	E	O,E	External Data/Comm. Links
Integrated System Checkout	E	E	O	E	E	E	O	Including Ext. I/F's & Equip.
Mission Sim. & Demonstration	E	E	O	E	E	E	O	H/W-In-The-Loop Rehearsal
Consumables Loading	E	E	O	E	E	E	O	Fluids, He, etc.
Propellant Loading	E	E	O	E	E	E	–	O2, H2, Hydrazine, etc.
Power System Activation	E	E	O	O	E	E	O	External Power Control
Propulsion System Activation	E	E	O	O	E	E	–	Pressurization, Chilldown, etc.
Internal Power Activation	E	E	O	O	E	E	O	Internal Power Control
Engine Ignition & Stabilization	O	O	O	O	O	O	–	Propulsion Engines
Launch Platform Separation	E	E	O	O	E	O	–	Includes Passive Release
Tracking	E	E	E	E	E	E	O	Active RF
Payload Checkout	O,E	E	O	–	E	E	O	Just Prior To Deployment
RMS Operation	O	–	O	–	E	E	O	Including Berthing
Payload Deployment	O	O	O	–	E	E	O	Separation From Vehicle
Rendezvous	O,E	–	O	–	O	O	O	Moving To Within Proximity
Payload Retrieval	O	–	O	–	E	E	O	RMS Or EVA
Docking	O	–	O	E	O,E	E	O	Includes Relate Prox Ops
Launch Abort	O,E	E	O,E	O	E	O	O	During Primary Prop. Phase
Mission Abort	E	E	O	O	O	O	O	Post Engine Shutdown
Reentry / Landing Abort	O	–	–	O	–	O	–	Recoverable Systems Only

O = On-Board, E = External

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OPERATIONS PARTITIONING
Responsibility For Operations (On-Board vs External)

OPERATION	STS	HLLV	MTV	ACRV	OMV	RR	CCC	COMMENTS
Fire Detection / Suppression	O,E	O,E	O	O	O	O	O	Internal Fire Only
ECLSS Failure Recovery	O	–	O	O	–	–	O	Backup Life Support Activation
Backup Power Activation	O	O	O	O	O	O	O	Assumes Potential Comm. Loss
Subsystem Shutdown / Recovery	O	O	O	O	E	E	O	On-Board For Complex System
Power System Deactivation	O,E	O,E	O,E	O,E	E	E	O	System-Level Shutdown
System Securing	E	–	O,E	O,E	E	E	O	Physical
System Safing	O,E	–	O,E	O,E	E	E	O	Chemical / Electrical
System Inspection	E	–	O,E	E	E	E	O	Overall Status
Subsystem Inspection	E	–	O,E	E	E	E	O	Unit-Level Status
Subsystem Repair	E	–	O,E	E	E	E	O	Incl. Module-Level Replace
Subsystem Changeout	E	–	O,E	E	E	E	O	Unit-Level Replacement
System Recertification	E	–	E	E	E	E	O	Verify Reusability

O = On-Board, E = External

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FINAL REPORT

AVIONICS OPERATIONS CAPABILITIES

AVIONICS CHARACTERIZATION
Definitions of Ratings

AVIONICS INVOLVEMENT
- The degree to which electronic systems, on-board or potentially on-board, carry out operations functions

HIGH – Avionics is the primary system involved, with little contribution from other systems

MEDIUM – Avionics has significant involvement, but contributions from other systems are required

LOW – Avionics has a supporting role in carrying out the operations functions

AUTOMATION POTENTIAL
- The degree to which tasks involving avionics can result in automated operations

HIGH – Operation can be fully automated

MEDIUM – Operation may require some manual input, inspection, checks, etc. but otherwise can operate relatively automatically

LOW – Operation requires significant manual involvement; automation is mostly limited to sub-operations or individual functions

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GENERAL DYNAMICS
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AVIONICS CHARACTERIZATION
Operations Suitable For Avionics Automation

OPERATION	AVIONICS INVOLVEMENT	AUTOMATION POTENTIAL
√ Health Management	HIGH: Analyze & store data; display results	HIGH: IHM technology development enables thorough autonomous health management
√ System Monitoring	HIGH: Collect health & status data; check against norms	HIGH: Sensor and processing technologies allow real-time monitoring of all critical systems
Data Acquisition	HIGH: Collect, transmit, receive, & store telemetry data	HIGH: No human interaction is required
Integration Checkout	MED: Verify interfaces & avionics functionality	MED: Non-avionics systems may require some manual checkout and verification
√ Avionics Verification	HIGH: Self-check; interface with test equipment	HIGH: Avionics technology development stresses testability and communication of results
Structural Verification	MED: Sensors at structural interfaces; embedded sensors	MED: Physical inspection of structural integrity will not involve avionics
Propulsion System Verification	MED: Engine controllers; TVC functions	MED: Prior to firing, avionics cannot determine engine status other than electronic components
√ Fluids System Verification	MED: Sensors for leak detection, pressures, etc.; Analysis	MED: Integration of fluids system will require some physical inspection
Electrical System Verification	HIGH: Current, voltage measurements; continuity checks	MED: Inspection of physical connectors and harnesses may be required

(√ = More Detail Documented)

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AVIONICS CHARACTERIZATION
Operations Suitable For Avionics Automation

OPERATION	AVIONICS INVOLVEMENT	AUTOMATION POTENTIAL
ECLSS Verification	MED: Subsystem & component checks	MED: Non-electrical interfaces may require some human inspection/verification
Ordnance System Verification	MED: Verify continuity (laser initiated pyros)	MED: Pyrotechnic devices cannot be checked electronically
√ Mission Simulation	HIGH: Exercise all systems/ subsystems	HIGH: Control and monitor functions are all electronic
Simulation Analysis	HIGH: AI/expert system analysis	HIGH: Electronic checks against nominal conditions
Emergency Proc. Validation	MED: Analysis of emergency procedures simulations	HIGH: Analysis via simulation fully automated by comparing results with desired parameters
√ Crew Training	HIGH: Avionics system in simulation mode	MED: Avionic system may be supplemented with manual input of training conditions
Crew Performance Evaluation	MED: AI/expert system analysis	MED: Expert system evaluation of training and mission performance
√ Mission Planning	MED: On-board planning; AGN&C real-time adjustments	MED: Automation of these functions may be supplemented by manual input or checks
Payload Integration	LOW: Verification of payload interfaces	MED: Payload interfaces are primarily electrical

(√ = More Detail Documented)

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AVIONICS CHARACTERIZATION
Operations Suitable For Avionics Automation

OPERATION	AVIONICS INVOLVEMENT	AUTOMATION POTENTIAL
External Interface Verification	MED: Electrical /Data interfaces with support equipment and integration/ launch facilities	MED: Physical inspection may also be required
Communications	HIGH: Integrated RF systems	HIGH: Communications system is all electronic
Data Loading	HIGH: System data interfaces & networks	HIGH: Data loading requires no human interface
Mission Control Interface Testing	HIGH: Verify communication/telemetry interfaces	HIGH: Interfaces are all electrical (landline) or RF (telemetry and communications)
Integrated System Checkout	MED: Supported with sensors & effectors	MED: Avionics related or controlled devices can be checked out autonomously
Mission Simulation & Demonstration (Final Checkout)	HIGH: On-board systems cooperating with ground systems	HIGH: Interfaces between ground and vehicle systems provide autonomous data transfer for simulation control and analysis
Consumables Loading	LOW: Monitor & control	MED: Significant monitor and control functions
Propellant Loading	LOW: Monitor & control	MED: Significant monitor and control functions
Power System Activation	HIGH: Power switching & monitoring	HIGH: Power system control is primarily through autonomous avionic systems

(√ = More Detail Documented)

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AVIONICS CHARACTERIZATION
Operations Suitable For Avionics Automation

OPERATION	AVIONICS INVOLVEMENT	AUTOMATION POTENTIAL
Propulsion System Activation	HIGH: Pressurization control; chilldown	HIGH: Avionics is primary control system
Internal Power Activation	HIGH: Power switching; monitoring	HIGH: Avionics is primary control system
Engine Ignition & Stabilization	MED: Initiation & condition monitoring	HIGH: Activities are performed according to automatic sequencing schedule
Launch Platform Separation	LOW: Simple commands	HIGH: Fully automatic function with significant mechanical (non-avionics) involvement
Tracking	MED: Transmission of nav. data; transponder response	HIGH: Avionics involvement, though low, is fully automated
Payload Checkout	HIGH: Control/monitor checkout process; telemetry I/F	HIGH: Payload checkout functions are primarily electrical and RF data, which are fully automated
RMS Operation	HIGH: Teleoperation I/F; automated procedures	HIGH: RMS is primarily avionics controlled
Payload Deployment	MED: Payload orientation & release commands	HIGH: Some mechanical systems are required, but control is through avionics
√ Rendezvous	HIGH: Nav. & control to within proximity ops region	HIGH: Fully automated rendezvous is mature technology

(√ = More Detail Documented)

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AVIONICS CHARACTERIZATION
Operations Suitable For Avionics Automation

OPERATION	AVIONICS INVOLVEMENT	AUTOMATION POTENTIAL
Payload Retrieval	MED: RMS/grapple operation	MED: Avionics aids human-controlled process
√ Docking	HIGH: Precision terminal guidance & control	HIGH: Fully automated docking is relatively mature technology
Launch Abort	HIGH: Sequencing & AGN&C	HIGH: Automated system and flight control
√ Mission Abort	MED: Mission replanning	MED: Analysis and contingency plan activation; still requires some human input and verification
Reentry / Landing Abort	HIGH: Sequencing & AGN&C	HIGH: Automatic control and planning functions performing in real time need autonomy
Fire Detection / Suppression	MED: Sensors & suppression system control	HIGH: Control and monitor functions can be fully automated
ECLSS Failure Recovery	MED: Sensors & backup system activation	HIGH: Fully automatic initiation and monitoring of backup system operation as well as status of primary system
Backup Power Activation	HIGH: Monitor & control in real time	HIGH: Avionics system directly monitors and controls power system automatically
Subsystem Shutdown/ Recovery	MED: Depends on subsystem (HIGH for avionics subsystem)	MED-HIGH: Some control possible over most subsystems; full control over avionics subsystems

(√ = More Detail Documented)

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AVIONICS CHARACTERIZATION
Operations Suitable For Avionics Automation

OPERATION	AVIONICS INVOLVEMENT	AUTOMATION POTENTIAL
Power System Deactivation	HIGH: Power switching and monitoring	HIGH All but most basic function can be automatically controlled
System Securing	MED: Deactivate and monitor subsystem status	MED: Some manual activity required after avionics shutdown
√ System Safing	LOW: Valve control; hazard monitoring: Other operations are manual	MED: Functions consistent with other mission phases can be relatively automatic
√ System Inspection	MED: Health management data download	HIGH: IHM data download fully autonomous
√ Subsystem Inspection	HIGH: (For avionics subsystems)	MED: IHM data analysis with manual inspection
Subsystem Repair	MED: (For avionics subsystems)	MED: BIT used for fault isolation and repair verification
Subsystem Changeout	MED: (For avionics subsystems)	MED: Subsystem BIT and automatic test procedures verify interfaces and functionality
System Recertification	MED: Health management data; system verification	MED: IHM data verifies system configuration and functionality; similar to integration and final checkout functions

(√ = More Detail Documented)

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SELECTED SECOND LEVEL OPERATIONS AND AVIONICS TECHNOLOGIES

PROCESSING
Health Management

System Components

Instrumentation/Sensors

Effectors (actuators, relays, valves)

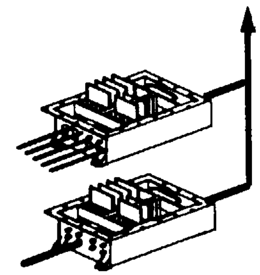
Interfaces To The Vehicle/System
- Command hardware

Applications Processing Hardware
- Processors, memory, buses,...

Data Storage Devices
- Tape (analog,digital)
- Disks (optical, magnetic)
- Computer memory

Data Networks/Distribution Systems

External Interfaces



Health Management Architecture

- Distributed HM processing
- Test and maintenance buses
- Smart sensors
- Built in test

Functions To Be Performed

Fault Isolation & Reconfiguration of Subsystems
- Avionic strings (masking & sparing)
- Non-avionic subsystems (sparing & shutdown)

Data Acquisition And Formatting Of:
- Commands and stimuli
- Processed bus traffic and sensor/effector data
- Raw bus traffic and sensor/effector data
- Built-In-Test data

Data Storage And Archive

Analysis Of Data (all mission phases)
- Fault/trend analysis, out-of-tolerance checks
- Sensor correlation & fusion
- Subsystem functionality
- Instrumentation functionality

Interface To External Processing/Monitoring

Desired Characteristics

- Automated data acquisition and distribution control
- Real-time analysis & control of subsystems
  - Fluids, propulsion, avionic reconfiguration
- Reduction of operations tasks and human errors
- Reduction of test & verification timelines

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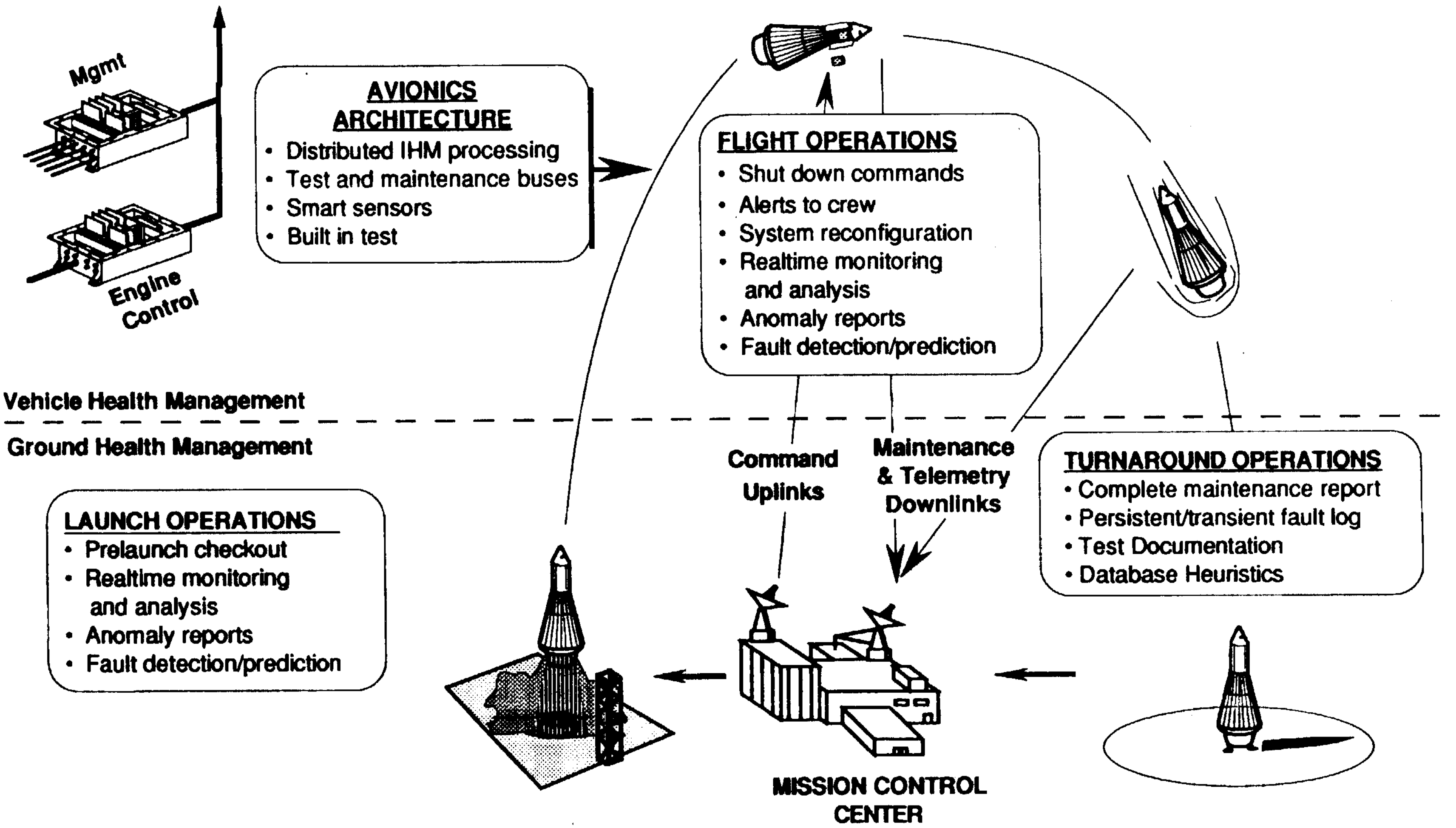
INTEGRATED HEALTH MANAGEMENT
Operational Infrastructure



IHM Is Present Throughout Flight And Ground Operations

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PROCESSING
Health Management

Automated Functions

INSTRUMENTATION FUNCTIONAL VERIFICATION	– Sensor failures account for a large portion of system anomalies. – Use of smart BIT and sensor fusion for higher fault detection.
DATA ACQUISITION CONTROL	– Enhanced calibration techniques, standardized / reconfigurable interfaces, microprocessor based-discrete interface cards. – Ability to perform data compression, linearization, trend and exception checking.
SUBSYSTEM FAULT ANALYSIS	– Use of distributed processing & sensor distribution for realtime onboard system health monitoring. – Distributed health analysis performed on major vehicle components (fluids, propulsion, avionics, ...) via AI, expert systems, BIT.
SUBSYSTEM RECONFIGURATION	– Appropriate corrective action performed to alleviate anomalies. – Possible maintenance downlink of critical information and approval requests to command or monitoring center.
DATA STORAGE	– Higher memory capacity enables larger storage of historical and analytical data. – Lower access time of data enables rapid recall for analysis and comparison; database heuristics. – Enables the use of common databases through real-time data networks; improves information dissemination.

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GENERAL DYNAMICS
Space Systems Division

PROCESSING
Health Management

Technical Requirements For Automation

SMART INSTRUMENTATION	– BIT, enhanced calibration, fault tolerant configurations
DATA ACQUISITION/ FORMATTING	– Microprocessor based, discrete interface cards – Software reconfigurable front end interfaces – Compatibility with vehicle hardware – Ability to perform data compression, linearization, trend and exception checking
DATA PROCESSING	– Increased throughput and memory – Distributed processing capability – Realtime operation
DATA STORAGE DEVICES	– Increased semiconductor memory capacity – Space qualification of components – Use of magnetic & optical disks, digital tape drives – Larger data mass storage capacity
APPLICATION PROCESSING	– AI, Expert systems – Distributed operating systems – Transparency of Health Mgmt to system operation
DATA NETWORKS /DISTRIBUTION SYSTEMS	– Enhanced throughput, fiber optic capability – Support common databases – Fault tolerant, reconfiguration capability – Environmental qualification

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HEALTH MANAGEMENT
Sensor Correlation/Fusion

Current Methods

- Data Analysis Tasks For Preflight And Postflight Comprise 15% And 65% Respectively Of The Overall Operations Costs For General Dynamics Launch Vehicles.
- Correlation Of Sensor Data Is Performed Visually By Analysts.
- Individual Sensors Used For Each Measurement Obtained, Instead Of Using Automated Correlation.
- Critical Pieces Of Vehicle Instrumentation Are Duplicated In Order To Provide Reliable Data.
  - Produces increased avionics size, power consumption, weight and harnessing requirements.
- Instrumentation Failures Account For A Large Portion Of Anomalies.
  - During prelaunch and flight, instrumentation accounts for ~59% of all anomalies for GD LV's.
  - Smart BIT instrumentation has not yet been widely implemented.
- Current Avionic Architectures Do Not Have Required Attributes To Perform Sensor Fusion On-Board.
  - No hierarchical test structure
  - Limited distributed processing
  - Limited real-time data distribution and storage capabilities
  - No use of smart instrumentation and Built-In-Test

Automated Correlation/Fusion Analysis Of Sensor Data Is Not Currently Performed.

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GENERAL DYNAMICS
Space Systems Division

HEALTH MANAGEMENT
Sensor Correlation/Fusion

Avionics Improved Method

- Intelligent Sensor Data Correlation And Fusion Across Vehicle Subsystems.
  - Utilizes artificial intelligence and expert systems technology.
  - Provides the capability for detection of abnormal performance, prediction of impending failures, and selection of an alleviating strategy once failures have occurred.
  - Can be performed on-board or external to a system.
- Reduction In Vehicle/System Instrumentation Requirements.
  - Instrumentation reduced by using non-redundant sensors coupled with sensor fusion analysis without a decrease in reliable data.
  - Instrumentation failures can be separated from actual subsystem failures.
- Correlation/Fusion Is Performed Onboard Via A Vehicle Health Management (VHM) System.
  - Requires an avionics architecture with distributed processing, test and maintenance buses, Etc.
- Sensor Correlation/Fusion Is Performed Externally Via Telemetered Or Direct Connected Data Sources.
  - Generally, external analyst systems have more resources available for highly detailed vehicle/system analysis, than onboard analyst systems (i.e. memory storage for database heuristics/trend analysis).
- GDSS Uses An Expert Analyst System, The Data Analysts Intelligent System (DAIS), To Evaluate Post-Flight Data From Atlas/Centaur Launches.
  - Accurately analyzes vehicle data much faster than manually possible and often produces results not readily apparent through traditional analysis.

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HEALTH MANAGEMENT
Sensor Correlation/Fusion

Avionics Enabled Savings

- Reduction Of Data Analysis Tasks Throughout A Mission.
  - Reduction of support equipment and personnel.
  - Application of GD's Data Analyst Intelligent System (DAIS) has, to date, produced a 20% reduction in post-flight data analysis manhours.
- Intelligent Correlation Of Available Data Reduces Required Instrumentation.
  - Reduced avionics size, power consumption, weight and harnessing.
- Reduction Of Delays Due To Instrumentation Failures.
  - Greater confidence in sensor data and system state.
  - Accurate failure detection of instrumentation enables possible fly-through of faults.
- Enables On-Board Health Management (Vehicle Health Management).
  - Realtime, onboard fault detection, isolation, recovery (FDIR) for long range operations such as SEI. Realtime FDIR can not be performed remotely due to excessive communication lag.
  - Provides alerts and/or approval authority requests to the crew or mission control.

Application Of Automated Sensor Correlation To Current GD Launch Vehicles Has Already Reduced Data Analysis Tasks.

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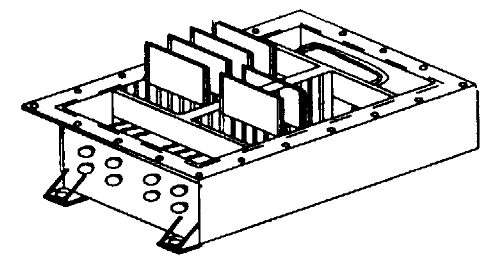
FINAL CHECKOUT
Avionics Verification



System Components

Inertial Measurement System
Communication And Tracking System
Data Processing
Memory
Buses
- Backplane
- System
- I/O

Input/Output Devices
Data Acquisition System
Effector Control System
Human Interfaces
Sensors
Effectors
External Interfaces (test, payload, etc.)

Functions To Be Performed

System, Subsystem, Module And Component Level Testing

Memory Verification

Configuration/Data Load Verification

Interface/Continuity Verification

Desired Characteristics Of Checkout

- Fully automated process
- Avoidance of system disconnection in order to test
- Integration and distribution of test results to health monitoring functions
- Full BIT capability of major components

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FINAL CHECKOUT
Avionics Verification

Automated Functions

CHIP LEVEL BIT MODULE BIT SUBSYSTEM LEVEL BIT	– The use of a hierarchical Built-In-Test structure to enhance subsystem functional verification. JIAWG common modules, for example, contain extensive BIT capabilities, including power up BIT and performance monitoring BIT. BIT information is made available on the subsystem level by dedicated test and maintenance buses. All detected faults are logged by a maintenance controller in the module's error log memory.
SUBSYSTEM SIMULATION	– Simulation, modeling and simulated control of inactive or hazardous subsystems enhances avionics functional verification and is made possible through distributed processing and simplified, common interfaces.
MEMORY ERROR DETECTION	– Use of enhanced error detection protocols used for higher fault detection coverage and verification of data loads. All detected faults are logged for analysis and traceability.
HARDWARE IDENTIFICATION	– Use of hardware identification nameplates in memory to enable system hardware configuration verification.
SENSOR VERIFICATION / SENSOR BIT	– The use of smart sensors, smart sensor fusion and fault tolerant comparison of redundant sensors to increase the detection of instrumentation failures.
SYSTEM CONTINUITY & CONFIGURATION VERIFICATION	– Use of autonomous configuration and continuity checking technology, such as Remote Sensor Cable Identification via passive hybrid chips installed in cables, connectors and transducers.

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FINAL CHECKOUT
Avionics Verification

Technical Requirements For Automation

SMART SENSORS, EFFECTORS & CONNECTORS	- Autonomous operational testing with high coverage of faults (>98%).
BUILT-IN-TEST (BIT)	- Hardware designed for testability at chip, module, subsystem and system level. High coverage of faults (>98%).
TEST BUS ARCHITECTURE	- Module, subsystem and system level test buses are required to pass test results and coordinate inter-unit testing. Operates at low data rates. Provides isolation from data buses.
FAULT/TREND ANALYSIS	- Automated analysis of data, identification of deviations from nominal conditions, selection of alleviating stratagem, and prediction of imminent failures.
ELECTRONIC COMPONENT MINIATURIZATION	- Reduction in size of memories, processors, connectors, Etc to enable increase processing power and reduced weight, power, Etc.

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AVIONICS VERIFICATION
Testing Procedures

Current Methods

- Present Avionics Do Not Support High Testability.
  - Very little Built-In-Test capabilities
  - Minimal amounts of "smart" instrumentation
  - Test results are not distributed to health management functions
- Checkout Procedures Required Large Amounts Of Ground Support Equipment And Interfacing.
- An Excessive Amount Of System Disconnection And Reconnection Is Required.
- Minimal Fault/Trend Analysis Is Performed On Components.
- Current Processes Require A Large Amount Of Support Engineers, For Long Periods Of Time.
- Instrumentation Has Large Calibration Requirements.

AVIONICS VERIFICATION
Built-In-Test

Avionics Improved Method

POWER UP BUILT-IN-TEST (BIT)	– Detects failures of module resources including: processor chip sets, resource controllers, data bus interfaces, maintenance controller chips, local memory, and supporting module logic
PERFORMANCE MONITORING BIT	– Consists of applications self-test software, initiated self-test software, and maintenance controller monitor firmware
OFF LINE BIT	– Designed to do complete testing of a module without interfering with overall system operation
MULTIPLE LEVEL BIT	– Different levels of testing are accomplished in each mode
- Level One	- Verifies intersubsystem capabilities and bus communication
- Level Two	- Verifies intermodule capabilities and bus communication
- Level Three	- Tests all module capabilities without stimulating outputs (e.g. Scan path testing)
SMART BIT SENSORS	– Allows capability to separate instrumentation failures from subsystem failures.

Avionics Enabled Savings

- Testing Procedures Can Be Fully Automated.
  - Reduction of external testing equipment and support personnel
- Elimination Of The Need For Disconnection And Reverification Of Interfaces.
- Helps To Reduce Delays Due To Rapid Failure Detection And Isolation.

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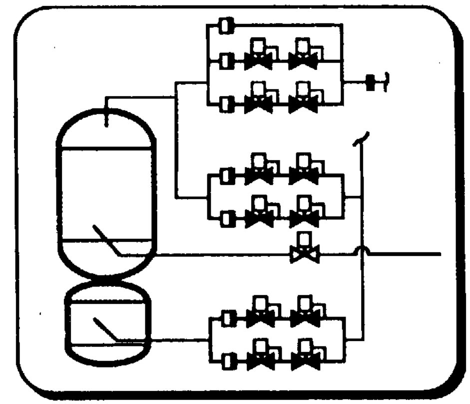
FINAL CHECKOUT
Fluids System Verification



System Components

Valves
- Relief
- Pneumatically actuated
- Purge
- Solenoid

Tanks
- Main propellant
- ACS
- Purge
- Pressurization

Plumbing (tubing, joints, fittings)

External Interfaces

Functions To Be Performed

Leak Tests (internal & external)

Valve Operation
- Open/close
- Actuation rates

Flow Tests

Fluid Level Checks

Temperature Checks

Pressure Checks

Desired Characteristics Of Checkout

- Eliminate the breaking of connections and/or retest
- Allow checkout at the operational conditions, if possible (temp, pressure, etc.)
- Distribute and integrate test results with Health Management, provide at least a GO/NO-GO status

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FINAL CHECKOUT
Fluids System Verification

Automated Functions

Leak Tests - leak mapping - ultrasonics - wide-field optical absorption - solenoid valve temperature	–	Locate and determine size of internal leaks past valve seats as well as external leaks through fittings, tubing, etc. without breaking the system.
Valve Operation Tests - Current Signature Test	–	Detect actuation time, valve health, and pull-in/drop-out voltages of solenoid valves remotely, without position switches.
- Pressure Signature Test	–	Determine minimum actuation/de-actuation pressure of pneumatically actuated valves without use of position switches.
Flow Test - Acoustic Purge Test	–	Non-intrusively detect flow through multiple purge lines.
Fluid Level Detection	–	Use of superconductivity, fiber-optic and laser technology to improve propellant level monitoring.

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FINAL CHECKOUT
Fluids System Verification

Technical Requirements For Automation

SPECTRAL ANALYSIS	- Analyze frequency spectrum for acoustic purge test. Frequency Range: 100 Hz – 10 kHz. Frequency Resolution: 100 Hz.
EXPERT SYSTEMS	- Rule based system to compare current and pressure signatures with nominal.
ELECTROMECHANICAL ACTUATORS	- Eliminates troublesome hydraulic systems.
CAPACITIVE FLUID PROBES	- Mature Technology
FIBER OPTIC FLUID DETECTORS	- Series of fiber optic sensors used to detect propellant level. Minimal avionic impact.
LASER FLUID DETECTORS	- Propellant level detected by surface reflecting laser and triangulation sensor.
FLOW METERS	- Mature Technology
PRESSURE REGULATORS	- Mature Technology
PRESSURE SENSORS	- Mature Technology
TEMPERATURE SENSORS	- Mature Technology
CURRENT SENSORS	- Mature Technology

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FLUIDS SYSTEM VERIFICATION
Functional Testing Of Valves

Current Methods

- Test Procedure Is Repetitive And Labor Intensive.
  - Disconnect power to the fluids system
  - Test using a GSE variable power supply
  - Manually test for actuation using pressure and current rise/drop, position switches, and sound/feel.
  - Reconnect and Re-leak check the system
- Process Requires Technically Trained Personnel Including Engineers, Quality Inspectors, Technicians, And Control Center Personnel.
- Test Result Distribution Is Poor And Paperwork Represents A Large Percentage Of The Task.
- Equipment Is Not Self-calibrating. Large Calibration Tasks Required.
- Instrumentation Failures, Including Position Switches, Account For A Large Portion Of Anomalies.
- Procedures Do Not Readily Support Launch Surging And Parallel Processing.
- Procedures Do Not Support Space-based Operations.

Fluid Systems Are Often "The Long Pole" During A Vehicle Checkout.

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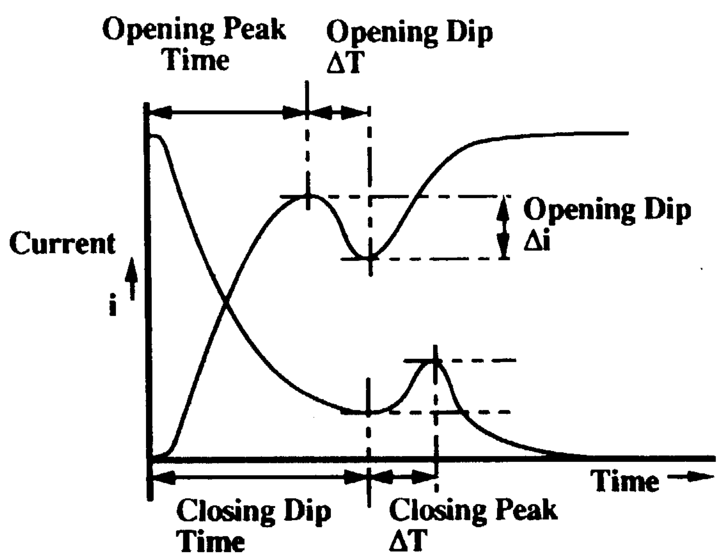
FLUIDS SYSTEM VERIFICATION
Functional Testing Of Valves

Avionics Improved Method

Current Signature Analysis for Solenoid Valves



PROCESS/PROCEDURE

1 Energize valve, acquire current vs. time.

2 De-energize valve, acquire current vs. time.

3 Identify characteristic parameters of curve.

4 Determine if each characteristic is within allowable band.

5 Simple expert system identifies specific failure based on high/low out of tolerance values.

PROCESSING REQUIREMENTS PER VALVE

Sampling Rate:	5	kHz
Sampling Duration:	0.25	seconds
Memory For Data Storage:	15	kbits
Memory For Algorithms:	5	kbits
Instructions Executed:	1.5	Million

fhm-05/13/91

FLUIDS SYSTEM VERIFICATION
Functional Testing Of Valves

Automated Operation Savings

- Elimination Of Tests Including Sound/Feel And Pull In/Drop Out Tests.
  - Reduction of valve checkout time. Valve verification via current signature analysis only requires a few seconds per valve.
  - Reduction in amount of re-testing required. Fluid lines are not broken to perform the test, no re-leak checking is required.
- Elimination Of Personnel Required Including Engineers, Quality Inspectors, And Technicians.
- Testing Procedures And Results Are Less Subjective And Require Less Documentation.
- Reduction Of Required Remove-Before-Flight And Fly-Away Instrumentation.
  - Elimination of troublesome Remove-Before-Flight instrumentation such as position switches
  - Elimination of associated data acquisition hardware

Current Signature Analysis For Fluid Valves Eliminates Many Tasks.

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TRAINING/SIMULATION
Mission Simulation/Crew Training

System Components

Simulation Equipment
- Processing
- Data storage
- Data networks

Human Interfaces
- Displays
- Flight controls
- RMS controls
- Sensory feedback

Functions To Be Performed

Flight Simulation

Docking Simulation

Landing Simulation

Manipulator Simulation

Emergency Procedure Simulation

Desired Characteristics

- Realistic Simulation of Actual Mission
- Accurate Evaluation of Performance
- Minimize External Hardware and Software

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GENERAL DYNAMICS
Space Systems Division

TRAINING/SIMULATION
Mission Simulation

Automated Functions

ENVIRONMENTAL CONDITION SIMULATION	- Simulate environmental coditions such as temperature, pressure, air mixture ratio and gravitional forces
VEHICLE DYNAMICS SIMULATION	- Simulate changing vehicle characteristics such as weight and center of gravity
ATTITUDE/CONTROL SIMULATION	- Simulate vehicle position and attitude given present course and speed
CREW INTERFACE SIMULATION	- Simulate displays and instrumentation readouts given present location and conditions
MANIPULATOR CONTROL SIMULATION	- Simulate manipulator position and movements from manipulator control inputs.

dja-07/10/91

TRAINING/SIMULATION
Mission Simulation

Technical Requirements For Automation

EFFECTOR MODELING	– Model state and condition of effector for input to simulations
SENSOR CONTROL	– Change sensor and/or sensor interface conditions to simulate changes in position, environment, etc.
COMPUTER SIMULATION	– Simulate changes in vehicle dynamics, attitude and environment given present state of simulation and state of effectors
COMPUTER GRAPHICS	– Create graphics necessary to monitor simulation and simulate crew interfaces
VEHICLE MODELING/ANALYSIS	– Model vehicle dynamics for computer simulation

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MISSION SIMULATION
Vehicle Modeling And Simulation

Current Methods

- Modeling And Simulation Tools Are Not Integrated And Streamlined.
  - Poor information and requirements dissemination
  - No common databases
  - Little or no automated design
  - Software coding performed manually
- Total System Modeling Is Not Performed Early In The Design Process, If At All.
- Does Not Utilize Reuseable Software.
- Crew Training Simulations Not Available On-Board.

MISSION SIMULATION
Vehicle Modeling And Simulation

Avionic Improved Operation

Models

Vehicle
- Rigid body (3-6 DOF)
- Flexible body
- Slosh (pendulum & spring)
- Aerodynamics
- Mass properties
- Sensors & effectors
- Bending, force & torque

Environment
- Gravity, Etc.

Equations Of Motion

Controllers
- Autopilot
- Guidance
- Estimators

Design & Simulation Environment

- Same Tools & Environment As Used For Flight Design & Integration*
  - Use of automated design tools
  - Common design database
  - Total system modeling
  - Iterative design & testing process
- Use Of Reusable Software Including Definition Of "User Code Blocks" For Vehicle Models
- Enhanced User Interfaces: pull-down menus, realtime data plots, output storage and retrieval
- Advanced Interface Capability For Training (displays, controls, Etc)

Simulations

Mission trajectories
Abort scenarios
Payload variations
Failures & off-nominal conditions

Test Results

Vehicle stability
Vehicle performance
Loads analysis
Robustness
Algorithm convergence

* see mission planning section

fhm-08/26/91

GENERAL DYNAMICS
Space Systems Division

MISSION SIMULATION
Vehicle Modeling And Simulation

Avionics Enabled Savings

- An Estimated Order Of Magnitude Reduction In Time Required To Generate Models.
- A Unified Environment Which Will Enable Onboard Vehicle Modeling And Simulation Potentially Required For SEI Missions.
- Part Of A Seamless Mission Design Environment Which Unifies Analysis, Modeling, Simulation, 2D & 3D Graphics And Automated Design And Software Generation.*
- Features Total System Simulation Which Increases Confidence In Design.

Use Of An Automated Design Environment To Enable Spaced-Based Vehicle Modeling And Simulation.

* see mission planning section

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MISSION PREPARATION
Mission Planning

System Components

Interfaces To The Vehicle
- Mission Control Hardware

Applications Processing Hardware
- Processors, Memory, Buses,...

Data Storage Devices
- Tape Drives (analog, digital)
- Disks (optical, magnetic)
- Computer Memory

Data Display Devices
- CRT's

Data Networks/Distribution Systems

External Interfaces
- Simulation Facilities
- Range

Functions To Be Performed

Mission Analysis & Integration Including The Generation,Validation And Formatting Of:

- Mission Parameters (performance, trajectory)
- Mission Software/Profile
- Schedules (mission, production, processing, flight)
- Service Requests
- Launch/Flight Plans
- Launch/Flight Support Documentation

Data Storage And Archive
- Standard Flight Plans
- Vehicle Configurations
- Contingency plans

Verification of Mission/Cargo/Range Safety Requirements

Mission Simulation

Resource management planning

Desired Characteristics

- Automated Generation Of Flight Software; Service Requests, Flight/Launch Plans, Schedules
- Standard Flight Profiles, Support Services
- Automated Logistics Planning And Tracking

MISSION PREPARATION
Mission Planning

Automated Functions

SCHEDULING; INCLUDING FLIGHT/LAUNCH PLAN	– Generate schedules for manufacturing and processing, given launch directive (contains database of mission/processing timelines)
FLIGHT DESIGN	– Including structural dynamics, guidance, control, trajectory performance, on-orbit, &contingency plans via streamlined rapid design and integration environment
FLIGHT SOFTWARE DESIGN & INTEGRATION	– Develop unique flight software from mission parameters (inclination, trajectories and insertion points) via streamlined rapid design and integration environment
ADAPTIVE GN&C	– Use of adaptive algorithms to handle wide variations in vehicle parameters (payloads, dynamic uncertainties, mission requirements)
RANGE OPERATIONS SUPPORT PLANNING	– Database of pre-approved information for a particular trajectory (including dispersions, flight corridors, instantaneous impact point, splash down points, and state vectors)
MISSION SIMULATION	– Verify specific flight/mission timeline and time correlated sequence of events
MISSION SUPPORT SCHEDULING	– Automate request process and information distribution of mission support requests

cq/fm-07/24/91

MISSION PREPARATION
Mission Planning

Technical Requirements For Automation

CASE TOOLS	– Including structured analysis tools, automatic code generators, debuggers, reverse engineering tools, control-coordinators, data repositories, and user interface tools. These tools are requirements for an efficient design & integration environment
PAPERLESS MANAGEMENT	– Distributed processing capability to access/interface with a distributed database - Increased storage capacity - Graphic displays
MISSION SIMULATION	– Simulation of flight and ground operations including crew interfaces and emergency procedures
EXPERT SYSTEMS	– Fault monitoring; realtime problem solving, diagnostics
AUTOMATED COMMUNICATION SCHEDULING	– Generates satellite and ground station usage schedules automatically
HEALTH MONITORING	– Support communication system status monitoring and reconfiguration
INCREASED PROCESSING CAPABILITIES	– Support adaptive GN&C concepts

cq/fm-7/25/91

MISSION PLANNING
Flight Design & Integration

Current Methods

- Time Consuming Process. Costs Millions Of Dollars To Perform For Launch Vehicles.
  - Atlas/Centaur mission planning takes ~1-2 years.
  - Requires 20-30K man hours.
- Inflexible/Non-reuseable: Recurring Cost For Each New Mission Or Payload.
- Software Maintenance Typically Consumes 60-80% Of Total Man Hours Required.
- Flight Designs Do Not Take Advantage Of Robust/Adaptive GN&C Concepts.
- Required Tasks Are Not Performed In An Integrated, Streamlined Manner. (Guidance, Control, Trajectory Performance, Structural Dynamics, Etc.)
  - No common databases for requirements, parameters, test results, Etc.
  - Poor information dissemination between required tasks.
  - Software requirements analysis and code generation is performed manually.
  - System testing is not performed until software and hardware is nearly (fully) developed.
  - Verification and validation of Hardware-In-The-Loop testing is only compared to analysis results and requirements. No model of the total system exists for comparison.

Current Mission Analysis & Design Process, Including Software Generation, Is Time Consuming And Labor Intensive.

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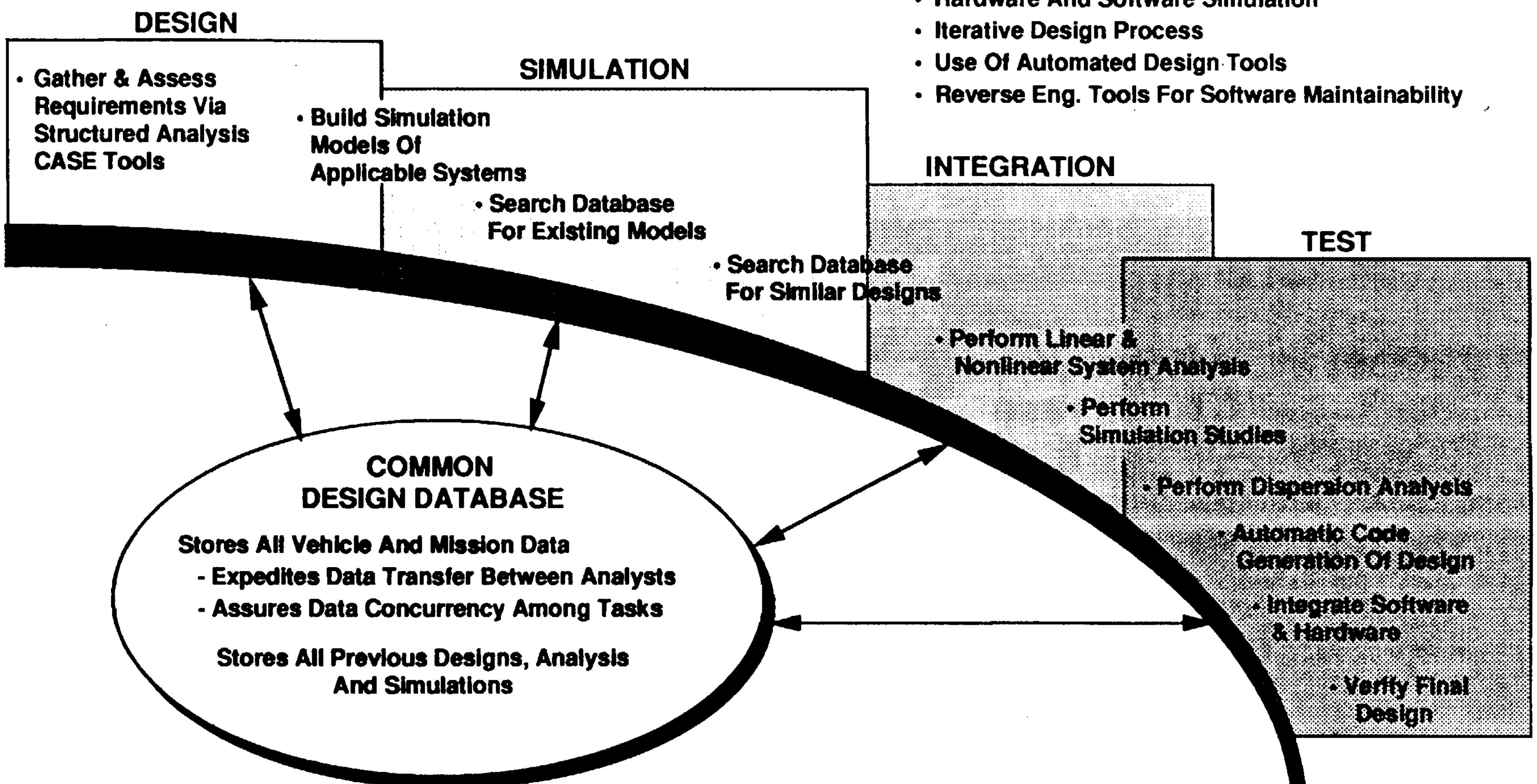
MISSION PLANNING
Flight Design & Integration
Avionics Improved Method

MISSION DESIGN SYSTEM
- Common Design Database
- Total System Modeling
- Hardware And Software Simulation
- Iterative Design Process
- Use Of Automated Design Tools
- Reverse Eng. Tools For Software Maintainability



SYSTEM PRODUCTS
- Software
- Simulations
- Documentation

An Integrated Streamlined Environment For Efficient Mission Design.

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MISSION PLANNING
Flight Design & Integration
Avionics Improved Method

Mission Design System - Description

- **Requirements Definition.**
  - Integration of all system requirements and parameters in a common system database.
  - Use of structured analysis CASE tools for requirements definition.
  - Initial software timing and size estimates, utilizing automatic software generation tools.
- **Modeling.**
  - By using appropriate tools, individual elements are integrated in total system model.
- **Design And Analysis.**
  - Individual as well as system level analyses
  - Utilizes common design and analysis tools
  - Uses specialized tools for certain specific tasks. Tools are integrated into the MDS.
- **System Test (Simulated).**
  - Utilize system test to refine requirements definition.
  - Ensures that the entire (simulated) system is working.
  - Allows system design errors to be discovered before HIL testing (i.e. before hardware is built).
- **Software Generation.**
  - Application and simulation software generated automatically.
  - Operating system developed manually (once), portions generated automatically.
  - Interface software developed manually, reconfigured automatically for new applications.
- **System Test (Hardware-In-The-Loop).**
  - Results compared to simulated system test, debugged by referring to system simulations.
- **Verification/Validation.**
  - Plant model and controller validated manually during design/analysis process.
  - Hardware, operating system, and interface software validated manually, once.
  - Process validation of automatically generated application and simulation software.
  - Validation is as good as the system models.

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MISSION PLANNING
Flight Design & Integration

Avionics Enabled Savings

- Significant Reduction In Man Hours Required (Estimated Order Of Magnitude Reduction).
  - Greatly reduced design and software maintenance requirements. (Software maintenance currently consumes 60-80% of total man hours)
  - Utilizes automated design and coding of simulation and application software.
  - GDSS' Mission Design System is predicted to reduce mission planning for GD Launch Vehicles from years down to months.
- Reduces Verification And Validation Costs.
  - Early system testing using models and simulations.
  - Integrated design environments create increased confidence in design and software.
  - Use of manually validated automated design tools.
- Process Streamlining And Automation Enables Space-Based Mission Planning Operations.
- Design Environments Support The Use Of Adaptive Algorithms Which Produce More Robust Designs.

Integrated Design Environments Will Produce Significant Reductions In Mission Planning Timelines.

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MISSION SUPPORT
System Monitoring

System Components

Interfaces To The Vehicle/System
- Data acquisition hardware

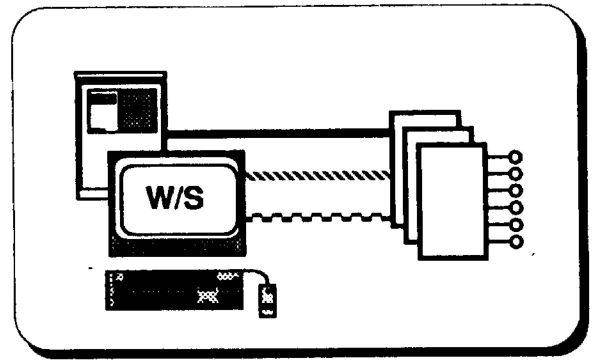
Applications Processing Hardware
- Processors, memory, buses,...

Data Storage Devices
- Tape drives (analog, digital)
- Disks (optical, magnetic)
- Semiconductor memory

Data Display Devices
- CRT's / Flat panel displays
- Stripcharts, oscillographs
- Meters, panels, lights

Data Networks/Distribution Systems

External Interfaces
- Experimental/developmental facilities
- Off-site locations
- Training and simulation facilities



Functions To Be Performed

Data Acquisition And Formatting Of:
- Commands and stimuli
- Processed bus traffic and sensor/effector data
- Raw bus traffic and sensor/effector data
- Built-In-Test data

Data Storage And Archive

Functional Verification Of System Components

Analysis Of Data
- Fault/trend analysis
- Out-of-tolerance checks
- Alerts to crew, external support, and/or system

Data Display

Interface To External Processing/Monitoring

Desired Characteristics Of Monitoring

- Automated Real-time Data Acquisition And Distribution
- Use Of Workstations For Data Display And Manipulation
- Application Of Health Monitoring

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MISSION SUPPORT
System Monitoring

Automated Functions

DATA DISPLAY
- Use of workstations and graphical displays to replace stripcharts, oscillographs, panels,...
- Data manipulation via simulated graphical stripcharts, menus and screen windows
- Enables efficient data display and lower labor requirements
- Operations support personnel are used more to solve problems and less to monitor, control and communicate

DATA STORAGE
- Higher memory capacity enables larger storage of historical and analytical data
- Lower access time of data enables rapid recall for analysis and comparison; database heuristics

DATA DISTRIBUTION
- Enables the use of common databases through real-time data networks; improves information dissemination

HEALTH MONITORING
- See next page

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GENERAL DYNAMICS
Space Systems Division

MISSION SUPPORT
System Monitoring

Automated Functions

HEALTH MONITORING

INPUTS
- Sensors/Effectors
- Built-In-Test
- Historical Database
- Command Data

FUNCTIONS PERFORMED
- Fault Detection
- Fault Prediction
- Trend/Pattern Analysis
- 'Smart' Sensor Fusion
- Database Heuristics
- Persistent/Transient Fault Logging
- Documentation Generation

REQMTS
- Expert Systems And AI
- Sensor and avionics BIT
- Distributed Processing
- Test and maintenance buses
- Real-time data distribution

OUTPUTS
- Alerts To Crew, Mission Support, Health Mgmt
- Maintenance Reports
- Fault Logs
- Test Documentation
- Historical Database

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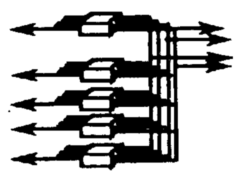
MISSION SUPPORT
System Monitoring

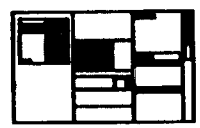
Technical Requirements For Automation

DATA ACQUISITION/ FORMATTING



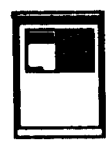
- Microprocessor based, discrete interface cards
- Software reconfigurable front end interfaces
- Compatibility with vehicle hardware
- Ability to perform data compression, linearization, trend and exception checking

DATA PROCESSING HARDWARE



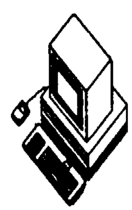
- Distributed processing capability and increased throughput and memory to support health monitoring

DATA STORAGE DEVICES



- Increased memory capacity
- Use of magnetic disk
- High density optical disks
- Digital tape drives

DATA DISPLAY DEVICES



- Use of work stations and graphical displays with trend and out-of-tolerance analysis capabilities
- Elimination of stripcharts, oscillographs, meters,...

DATA NETWORKS /DISTRIBUTION SYSTEMS

System Command Bus

System Data Bus

Local Area Network

- Enhanced throughput, fiber optic capability

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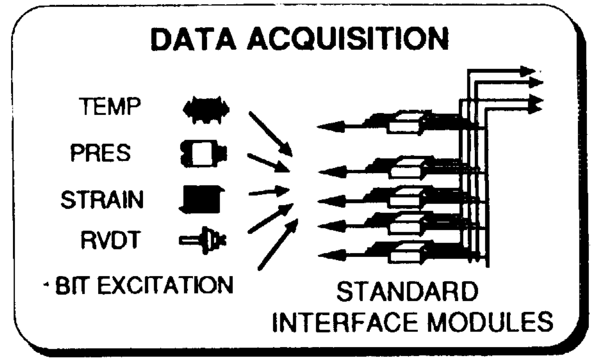
SYSTEM MONITORING
Data Acquisition Hardware

Current Methods

- Application Specific, Non-Reconfigurable Hardware.
  - Dedicated input lines for each measurement.
  - Each piece of instrumentation has dedicated circuitry to perform excitation, sampling and formatting.
  - Unique hardware for each type of sensor and measurement.
  - Non-programmable. Not configurable to support sensors with multiple operational modes.
- Federated Data Acquisition Systems.
  - Primary vehicle data acquisition hardware funnels most data to the telemetry and landline interfaces.
  - Separate hardware routes data to the flight control and vehicle management systems.
- Hardware Does Not Support Automated Checkout Capabilities.
  - Data is not distributed globally across subsystems.
  - Limited BIT capabilities.

SYSTEM MONITORING
Data Acquisition Hardware

Avionics Improved Method



- Standardized Data Acquisition Modules.
  - Each module is identical in design (analog or digital) and microprocessor based.
  - Each channel of a module can be programmed to receive a variety of sensor inputs (temp, LVDT, ...).
  - Baseline designs capture 95% of all existing launch vehicle measurement types.
  - Digital: Collects discrete and frequency generating measurements.
  - Analog: Collects inductive, resistive, current and voltage measurements.
- Hardware Supports Improved Testability.
  - Sensor data is made available to all subsystems to support health management functions.
  - Hardware supports and enables BIT capabilities.
  - Software Reconfigurable Hardware: Each channel has individually programmable gains & offsets. Sensors which have multiple operational modes during different mission segments are more easily tested (e.g. Sensors which measure various cryogenic temperature ranges).
- Enhanced Data Formatting Capabilities.
  - The interface cards fully support various data formatting and filtering functions including data compression, linearization & engineering units conversion.

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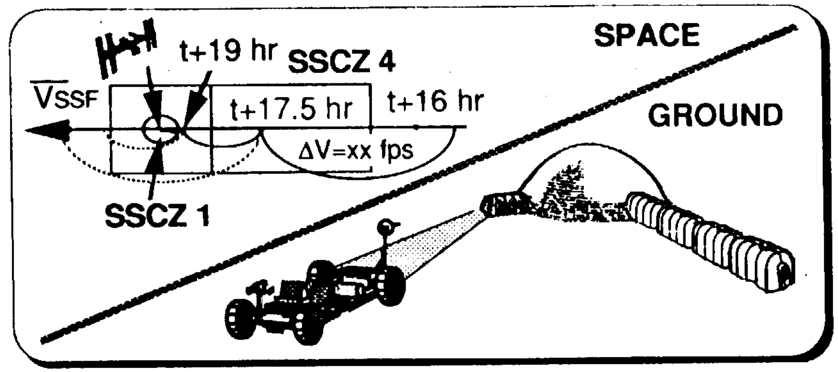
SYSTEM MONITORING
Data Acquisition Hardware

Avionics Enabled Savings

- Scalable, Reconfigurable Hardware Reduces Recurring And Non-recurring Costs.
  - Lower DDT&E costs. Standardized hardware meets 95% of data acquisition requirements.
  - Reduces vehicle instrumentation requirements. Hardware can be reprogrammed for various sensors
  - Reduces data acquisition harnessing size and weight.
- Standardized Modules Enable Distributed Data Acquisition Throughout A Vehicle/System.
  - Hardware is designed to interface with system databuses.
- Improved Testability.
  - Standardized, microprocessor based modules fully support BIT and automated checkout.

GENERAL DYNAMICS
Space Systems Division

MISSION SUPPORT
Rendezvous And Docking



System Components

Inertial Navigation System
Optical Sensors
Imaging System
GPS receivers
Communication Systems
Radar/Ladar Transceivers
Docking Sensors

Functions To Be Performed

Rendezvous Target Acquisition
Communication and Tracking of Target
GN&C
Collision Avoidance / Debris Deconfliction
Contamination Avoidance
Docking
Operation In Various Modes:
- Autonomous
- Supervised automatic
- Teleoperated
- As a monitor during manual operations

Desired Characteristics Of Required Components

- Use Of Integrated Sensor Suites Capable Of Supporting All Proximity Operations
- High Reliability And Accuracy
- Commonality To Support A Wide Range Of Vehicles

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MISSION SUPPORT
Rendezvous And Docking

Automated Functions

RENDEZVOUS	– Initial acquisition of target and proper alignment, positioning, and velocity inside of control zones in multiple levels of autonomy including supervised automatic and fully autonomous
DOCKING	– Use of required sensors, navigation aids and processing to perform operation in multiple levels of autonomy
COLLISION AVOIDANCE / DEBRIS DECONFLICTION	– Capability to acquire or detect deconfliction information and take proper action
CONTAMINATION AVOIDANCE	– Vehicle or system should be capable of preventing contamination to host target (i.e. plume impingement)
COMMUNICATION &TRACKING	– Ability to monitor flight and safety critical systems of target and provide "wave-off" commands if necessary – Ability to command and reconfigure target to a safe configuration

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MISSION SUPPORT
Rendezvous And Docking

Technical Requirements For Automation

INTEGRATED GPS/INS	– Provides initial attitude, position, and range information to the flight control system for proximity operations
IMAGE PROCESSING	– Should have capability to extract important range and attitude characteristics from target (see the following page)
IMAGING CAMERAS	– Should have frame capture capability for image processing
CAMERA/MIRROR ALIGNMENT SYSTEM	– Provides highly accurate attitude and position information for final docking alignment
LADAR/RADAR	– Provides accurate range resolution and rate information.
TRACKING	– Should provide the required accuracy needed for operations with a variety of systems and for collision avoidance
COMMUNICATION	– Should have the bandwidth required to receive and transmit all monitor and control information for proximity operations

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MISSION SUPPORT
Rendezvous And Docking

Current Methods

- Requires Multiple Systems For Various Rend. & Docking Phases.
  - Uses different systems for initial target acquisition to final docking phase.
- Unable To Perform Fully Autonomous Rend. & Docking.
- Marginal Docking Accuracy.
  - Range resolution of only 1.5m during final docking phase.
  - Range rate accuracy only 0.3m/sec during final docking phase.
- Marginal Reliability (<0.98). Significant Risk Of Damage To The Vehicle And The Docking Target.

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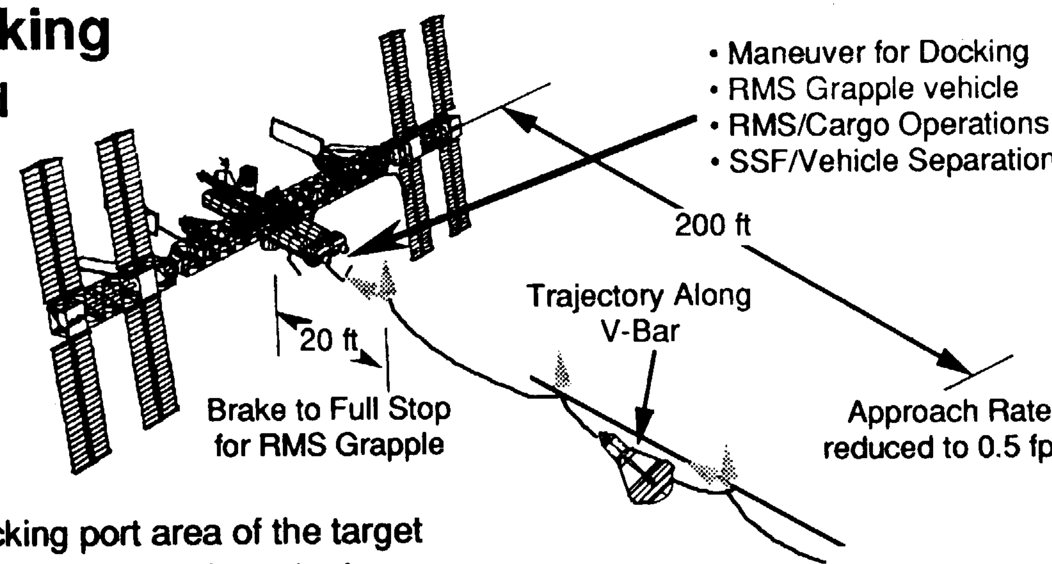
MISSION SUPPORT
Rendezvous And Docking
Avionics Improved Method

Digital Imaging System



FUNCTIONS

- Obtain imagery of the docking port area of the target
- Extract the docking port target pattern from the imagery
- Determine range to the target by analyzing the target size
- Determine vehicle attitude with respect to the target by analyzing distortions in the pattern shape
- Pass the vehicle range and attitude data to the vehicle guidance computer

REQUIREMENTS

IMAGE PROCESSING	– Analysis of frame by frame video data
	– High throughput via parallel processing 100's of MIPS and MFLOPS
	– Memory requirement: 10-100's of Mbytes
	– Hardware should be compatible/common with avionics
IMAGING CAMERAS	– Should have frame capture capability for image processing

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C-2

MISSION SUPPORT
Rendezvous And Docking

Avionics Enabled Savings

- Contributes To Higher Reliability Due To Fewer Components And Tighter Integration.
  - Reliability goal of 0.9999.
- Higher Docking Accuracy Than Current Methods.
  - Provides range resolution of 1.0% of range and 0.005m during final docking phase.
  - Provides range rate of 0.3% of range and 0.003 m/sec during final docking phase.
- In Conjunction With An Integrated System, Enables R&D To Be Performed In Various Modes.
  - Autonomous, supervised automatic, teleoperated, monitor.
- Replaces Multiple Systems Required For Various R&D Phases.
  - Imaging system can be used from initial target acquisition to final docking phase.

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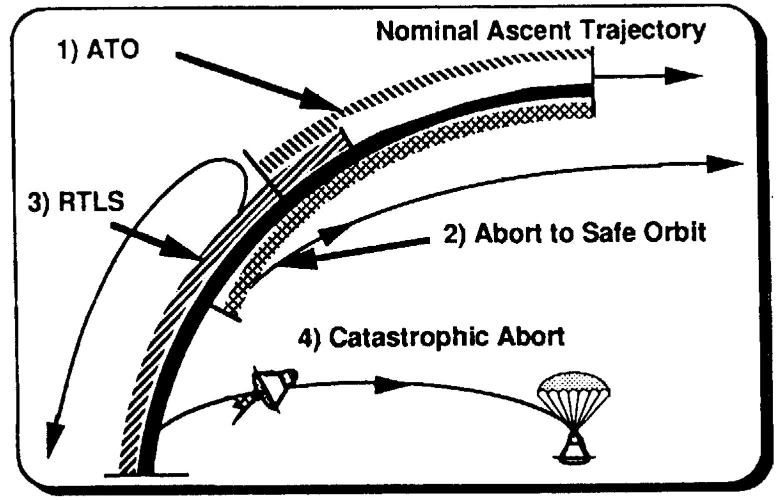
EMERGENCY PROCEDURES
Mission Abort



Functions To Be Performed

Mission Replanning

Emergency Systems Activation

Backup System Activation

Failure/Damage Assessment

Risk Assessment

Desired Characteristics

- Insure Safety of Crew and Civilians
- Reliable Activation of Emergency and Backup Systems
- Robust Mission Replanning
- Reliable Assessment of Conditions that Cause Mission Abort

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EMERGENCY PROCEDURES
Mission Abort

Automated Functions

FAULT/DAMAGE ASSESSMENT	–	Identify vehicle failures and damage. Assess ability of vehicle to perform alternate missions, maneuvers and courses.
BEST RETURN SITE ID	–	Identify best available return site given mission scenario, location, and fault/damage assessment.
COURSE SELECTION/PLANNING	–	Determine best course to reach chosen return site.
GUIDANCE AND NAVIGATION	–	Vehicle attitude control for trajectory changes. Must handle engine out, rendezvous, docking and other hazards.
EMERGENCY/BACKUP SYSTEM ACTIVATION	–	Ensure that appropriate damage control and backup systems for critical functions are activated and working properly

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EMERGENCY PROCEDURES
Mission Abort

Technical Requirements For Automation

ADAPTIVE GUIDANCE, NAVIGATION AND CONTROL	– Trajectory planning for off-nominal flight conditions including: payload variations, winds aloft, and engine out.
POSITION LOCATION	– Location needed to select return site and course.
HEALTH MONITORING	– Monitor subsystem to detect faults or damage sustained during flight.
ARTIFICIAL INTELLIGENCE	– Evaluate fault/damage assessment, mission goals and location to determine risk, course and return site.
SENSOR DATA ACQUISITION	– Monitor systems required for mission abort and replanning.

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MISSION ABORT
Adaptive GN&C Concepts

Current Methods

- Onboard Autonomous Abort Planning Required For SEI Is Not Currently Used.
  - Ground-based abort planning, which covers all abort scenarios, is not possible to do a priori.
  - For long distance missions, such as Lunar/Mars, Earth-based abort planning will not be capable of quick abort responses do to large communication lags.
  - Does not produce optimal Abort Options.
- Large Support Networks are Required For Various Abort Scenarios.
  - Communication & tracking equipment, landing site navigation aids, support personnel.
- Current Systems Are Inflexible To Non-Ideal Conditions At Abort Landing Sites.
  - Must Be Nominal At Abort Landing Areas Before Launching.

MISSION ABORT
Adaptive GN&C Concepts

Avionics Improved Method

ADAPTIVE OPTIMAL THRUST RESOLVER	– Automatically compensates for engine failures. – Minimizes required thrust variations. – Allows for varying amounts of c.g. pointing by each engine.
COMMAND MULTIPLIER STEERING	– Modification/generation of pitch rate tables during flight to meet mission requirements with engine out.
ADAPTIVE BENDING FILTER	– Adjusts to vehicle dynamics resulting from changes in vehicle state and payload. – Use of adaptive notch filters to automatically identify and track vehicle bending frequencies. – Removes vehicle bending effects from sensor data.
DYNAMIC INVERSION CONTROL	– Optimizes vehicle control parameters throughout flight profile through use of an onboard estimator of vehicle parameters. Useful for rapid generation and optimization of mission abort flight trajectories.
SLOSH ESTIMATOR	– Keeps fuel slosh effects from causing vehicle instability.
LIDAR FOR WINDS ALOFT ESTIMATION	– Enables trajectory compensation of winds aloft during flight.

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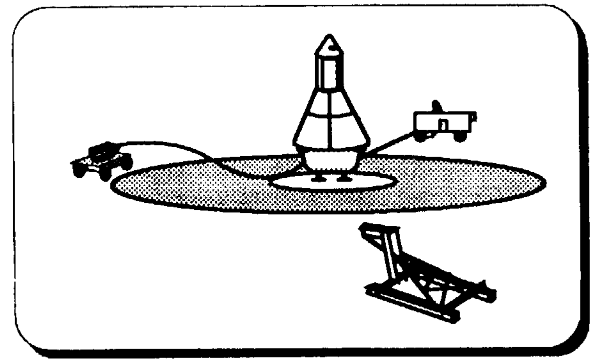
MISSION ABORT
Adaptive GN&C Concepts

Avionics Enabled Savings

- Adaptive GN&C Concepts Will Enable Onboard Autonomous Contingency Planning Required For SEI.
  - Ground-based abort planning, which covers all failure scenarios, is not possible to do a priori.
  - Impossible to do remotely due to large communication lags.
- AGNC Concepts Widen Acceptable Launch Conditions.
  - Increased vehicle robustness to various conditions: engine out, payload variations, winds aloft, Etc.
  - Decrease the number conditions which require an abort (increased vehicle robustness).
  - Decrease in launch delays due to off-nominal conditions. Less dependency on abort site conditions.
- Reduces Logistical Requirements Of Support Networks Through Increase Vehicle Robustness.
  - Produces real-time continuous abort analysis for optimal abort trajectories and abort options.
  - Higher vehicle autonomy/robustness reduces communication & tracking equipment, abort landing site equipment and support personnel.

RECOVERY
System Safing



System Components

Propulsion Systems

Fluids Systems

Mechanical Systems

Pyrotechnics

Electrical Power Systems

ECLSS

Storables

Functions To Be Performed

Propellant Discharge

Off Loading Of Hazardous Storables

Pyrotechnic Safing

ECLSS Shutdown

Electrical Power System Shut-Down

Propulsion And Fluids System Shut-Down

Desired Characteristics

- Reliable Safing Of All Subsystems
- Minimize Impact To Environment
- Allow For Easy System Restart

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RECOVERY
System Safing

Automated Functions

CRYOGENIC RECOVERY	-	Download and store cryogenic fluid for future use. Maintain safe on-board storage, if practical.
TOXIC MATERIALS RECOVERY	-	Recovery or disposal of toxic material including propellants and waste.
NON-TOXIC MATERIALS RECOVERY	-	Recovery or disposal of non-toxic material including propellants and waste.
POWER SYSTEM SHUTDOWN AND MONITORING	-	Control sequencing for power system shutdown. Monitor system to insure safe shutdown
PYROTECHNIC ISOLATION	-	Isolate pyrotechnics from control and power for fail safe shutdown
PROPULSION SYSTEM SHUTDOWN AND MONITORING	-	Control sequencing for propulsion system shutdown. Monitor system to insure safe shutdown

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RECOVERY
System Safing

Technical Requirements For Automation

SENSOR DATA ACQUISITION	- Monitor systems critical to the safety of the crew during recovery.
VALVE CONTROL	- Actuate valves for material recovery
RELAY CONTROL	- Actuate relays for propellant and power system shutdown sequencing.
FLUID LEVEL SENSING	- Accurately monitor fluid levels for cryogenic, toxic material and non-toxic material recovery.
VOLTAGE/CURRENT SENSING	- Monitor voltage and current for power system shutdown

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SYSTEM SAFING
Pyrotechnic Systems

Current Methods

- Current Systems Can Not Be Completely "Closed-out" At Off-Site Processing Locations.
  - Requires additional processing, precautions and personnel at the launch site.
  - All operations must be interrupted while explosives are installed or safed.
  - Requires additional access doors on the vehicle, and flip-down decks and platforms on the tower.
- Limited Health Monitoring Capabilities.
  - Circuit continuity & bridgewire resistance checks.
- Unable To Perform Firing Circuitry Functional And Full Energy Verifications.
  - Concern over pyro initiation.
- Only Manual Methods Of Inhibitor Verification Are Available.
- Electrical Transfer Systems Are Susceptible To Inadvertent Initiation By Currents Induced By EMI, RFI & Static Charges.
- Explosive Transfer Systems Have No Means Of Continuity Or Propellant Quality Verification.
  - No means of automated monitoring or in-place inspection.
  - Some systems require waivers to range safety regulations.

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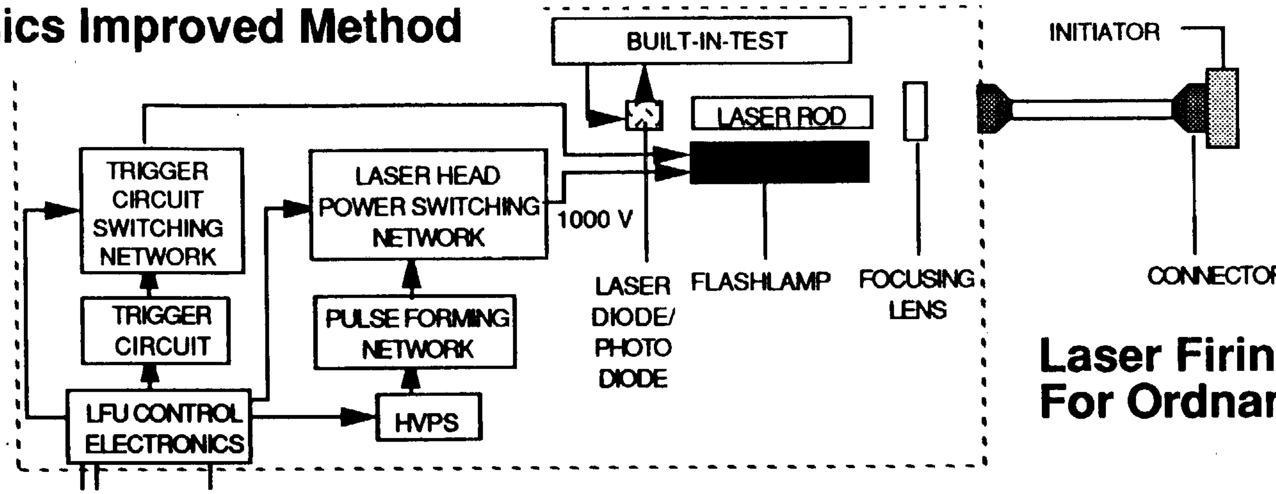
Space Systems Division

SYSTEM SAFING
Pyrotechnic Systems
Avionics Improved Method



Laser Firing Units For Ordnance Initiation

OPERATIONAL IMPROVEMENTS

- LFUs And Ordnance Can Be Installed And Safed Without RF Silence.
- Increased System Testability Provides Autonomous System Verification.
  - Automated means of inhibitor verification
  - Verification of response to input signals from command and control source
  - Internal firing diagnostics, functional verification of all components
  - Diagnostics of transmission systems, continuity and energy transmissivity
  - Diagnostics of pyrotechnic devices, propellant to interface contact and propellant chemistry
  - Controller full energy output testing
  - Interface avionics transmit health data in addition to instrumentation and control data

RELIABILITY

- No Moving Parts.
- Fiber Optic Lines Insensitive To RF, EMI, Etc.
- Initiator Only Sensitive To A Specified Frequency.
- High Voltage Required To Fire Laser.

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SYSTEM SAFING
Pyrotechnic Systems

Avionics Enabled Savings

- A Standard Laser Initiator Will Improve Pyrotechnic System Safety.
  - Increase in system reliability. Fiber-optic connections are immune to EMI & RFI, no moving parts.
  - Reduced human involvement in system safing process through automated.
  - Higher confidence in system verification due to advanced testing techniques.
    (i.e. Remote optical time domain reflectometry, Propellant spectrographic analysis, BIT capabilities).
- Reduction Of Vehicle Hardware Costs.
  - Placement of diagnostic equipment on the ground, rather than on-board.
  - Estimated cost savings of $0.1 million per HLLV.
  - Reduction of weight and size of hardware.
    (Less routing of pyro initiation harnessing required to avoid high EMI areas. Lower shielding needs)
- Reduced Operations Costs.
  - Required safing operations are simplified. Reduction of launch/retrieval site personnel.
  - More safing operations can be performed remotely from a command center.
- Fiber-Optics Provide Safe Means To Verify Pyrotechnic Initiation Transfer.

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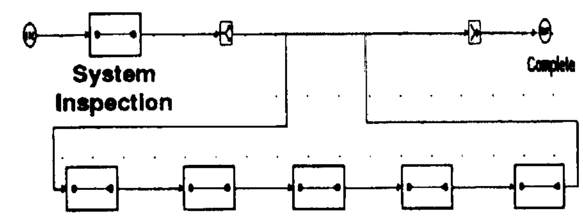
REFURBISHMENT/MAINTENANCE
System Inspection



Functions To Be Performed

Download Vehicle/System Stored Raw Data And Test/Maintenance Data

Physically Inspect System

Perform Diagnostics Of The Vehicle/System

Perform Prognostics

Determine Required And Preventive Maintenance Procedures And Process Flows

Document And Distribute Diagnostics, Prognostics And Maintenance Plans

Desired Characteristics

- Reliable And Accurate Diagnosis Of Vehicle/System State
- Automation Of Diagnostic, Prognostic Procedures
- Isolation Of Faults To Lowest Possible Levels (i.e. subsystem, module, Etc.)
- Optimization Of Required Maintenance Procedures
- Automated Documentation Generation And Information Distribution

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REFURBISHMENT/MAINTENANCE
System Inspection

Automated Functions

DATA DOWNLOAD	– Use of downloaded raw, health, and maintenance data to aid the refurbishment and maintenance process.
VEHICLE/SYSTEM DIAGNOSTICS	– Performed through use of downloaded data, ground test results and AI/expert system analysis of vehicle systems. Should be capable of isolating faults to the lowest possible level.
VEHICLE/SYSTEM PROGNOSTICS	– Utilizes AI and expert systems to perform trend/fault prediction, pattern analysis,reliability predictions and FMEA.
MAINTENANCE SCHEDULING	– Use of AI and expert systems to optimize the maintenance process.
DOCUMENTATION GENERATION	– Use of computerized environment capable of autogenerating required test and maintenance results and procedures.
DIAGNOSTIC AND SCHEDULING INFORMATION DISTRIBUTION	– Use of computerized environment capable of distributing required test and maintenance results and procedures in an efficient, timely manner.

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REFURBISHMENT/MAINTENANCE
System Inspection

Technical Requirements For Automation

ARTIFICIAL INTELLIGENCE/ EXPERT SYSTEMS	–	Analyze health management data to determine the health of the system. Isolation of faults to the lowest possible level (e.g. Line replaceable unit).
HEALTH MONITORING*	–	Monitor system to detect and predict faults.
TEST BUS ARCHITECTURE	–	Module, subsystem and system level test buses are required to pass test results and coordinate inter-unit testing. Operates at low data rates. Provides isolation from system data buses and normal application processes.
DATA DISTRIBUTION, STORAGE AND PROCESSING	–	Enables large amounts of realtime applications processing such as health management functions.

* See health management and system monitoring sections

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SYSTEM INSPECTION
Test & Maintenance Buses

Current Methods

- Present Vehicles Do Not Contain An Independent Test Bus Structure Needed For Distribution Of Test, Maintenance And System Health Information.
  - Vehicles do not analyze raw data to produce test results and maintenance requirements.
- System Inspections Are Performed Using Manual Methods To Check Continuity And Vehicle Functions.
  - Labor intensive, time consuming process.

Avionics Improved Method

- A Test And Maintenance Bus Structure Is Critical To Achieving Health Monitoring Functions That Are Independent From System Operation.
  - Provides an independent network to distributed health, maintenance and BIT .
  - Enables testing in a various modes of operation (e.g. powered down, degraded, full up, in parallel).
- Provides A Simple Mechanism For External Test Equipment Interfacing And Test Data Retrieval.

REQUIREMENTS

- Use of TM Buses In Subsystems For Independent Distribution Of TM Data Throughout The Subsystem.
- Use Of A Test And Maintenance Coordinator.
  - Responsible for assuring proper communication protocols among TM buses.
- A System Test and Maintenance (STM) Network.
  - Used by the Test and Maintenance Coordinator to distribute system wide TM data.

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SYSTEM INSPECTION
Test & Maintenance Buses

Avionics Enabled Savings

- Enables Onboard Health Management Functions And System Wide Distribution Of Test Data.
- Reduces Required Manual Inspection Tasks.
  - Continuity and system functional verification can be performed through the TM-bus structure.
- Aids Isolation Of Faults To The Lowest Possible Level.
- Reduces Vehicle And External Instrumentation Requirements Through Increased System Testability.
- Increases Vehicle/System Reliability.
  - Provides an independent and isolated communication path for system wide fault detection, isolation, and restoration information.

Test And Maintenance Buses Reduce Manual System Inspection By Enabling System Wide Health Management.

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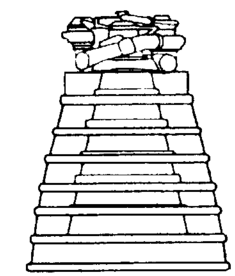
REFURBISHMENT/MAINTENANCE
Subsystem Inspection – Propulsion



System Components

Cryogenic Engines, Electric Motors
Reactors, Etc

Pumps
Thrust Chambers
Injectors
Generators
Nozzles
Valves
Interconnects (tubing, joints)
Actuators
Engine Controllers

Functions To Be Performed

Download Vehicle/Engine Data
Inspect Components
- Borescope,Videoscope, Etc

Perform Diagnostics/Prognostics
- Torque Checks
- Pressure Leak Tests
- Axial Travel
- Valve Checks
- Various Functional Verifications
- Engine Drying

Document/Distribute Results
Determine/Distribute Maintenance Plans

Desired Characteristics

- Minimize Manual Inspection
- Distribute Test Results to other System Components or External Systems
- Reliable Determination of System Operational Capability

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REFURBISHMENT/MAINTENANCE
Subsystem Inspection – Propulsion

Automated Functions

DATA DOWNLOAD	–	Use of downloaded raw, health, and maintenance data to aid the inspection and refurbishment/maintenance process.
DIAGNOSTICS/PROGNOSTICS - Leak, torque, valve tests, Etc.	–	Performed through use of downloaded data, ground testing and AI/expert system analysis of vehicle systems. Should be capable of isolating faults to the lowest possible level.
MAINTENANCE SCHEDULING /DOCUMENTATION GENERATION	–	Use of AI and expert systems to optimize the maintenance process. Use of computerized environment capable of autogenerating required test and maintenance results.
DIAGNOSTIC AND SCHEDULING INFORMATION DISTRIBUTION	–	Use of computerized environment capable of distributing required test and maintenance results and procedures in an efficient, timely manner.

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REFURBISHMENT/MAINTENANCE
Subsystem Inspection – Propulsion

Technical Requirements For Automation

ADVANCED INSTRUMENTATION –	Reduces post-mission inspection requirements by enabling analysis of propulsion system operation during the flight.
ARTIFICIAL INTELLIGENCE/ EXPERT SYSTEMS –	Analyze health management data to determine the health of the system. Isolation of faults to the lowest possible level (e.g. Line replaceable unit).
HEALTH MONITORING* –	Monitor system to detect and predict faults.
TEST BUS ARCHITECTURE –	Module, subsystem and system level test buses are required to pass test results and coordinate inter-unit testing. Operates at low data rates. Provides isolation from system data buses and normal application processes.
DATA DISTRIBUTION, STORAGE AND PROCESSING –	Enables large amounts of realtime applications processing such as health management functions.

* see health management and system monitoring sections

SUBSYSTEM INSPECTION – PROPULSION
Advanced Maintenance Sensors
Current Methods

- Instrumentation Requirements For Inspection And Maintenance Are Different Than For Mission Success.
  - Most instrumentation emphasizes flight critical components rather than high maintenance ones.
  - Most subsystem inspection performed manually with extensive GSE.
  - Limited use of Fly- Away maintenance related instrumentation or post-flight maintenance downloading.
- Mission Success Related Instrumentation Does Not Detect All Engine Failure Modes.
  - Does not aid ground inspection, GSE, and maintenance requirements.
  - Some failure modes can only be easily observed during propulsion system operation.
- Reduction In Component Catastrophic Failure Rates Results In Increased Component Maintenance Rate.
  - Currently, systems do not use instrumentation required to meet increased maintenance rates.
  - Focus has only been on high inflight reliability, not reduced maintenance.
- Currently Available Sensors (not necessarily used).
  - Thermocouple
  - Eddy Current
  - Inductive Debris Monitor
  - Limit Switches
  - Accelerometers
  - Resistance Temperature Detector
  - LVDT/RVDT

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SUBSYSTEM INSPECTION – PROPULSION
Advanced Maintenance Sensors
Avionics Improved Method

Sample Listing

SIMPLE STATE OF THE ART	COMPLEX STATE OF THE ART	LONG TERM TECHNOLOGY
Capacitive Pressure	Acoustic Emission	On-board Plume Spectroscopy
Capacitive Blade Clearance	Fiber-optic Deflectometer	On-board Mass Spectroscopy
Silicon-on-sapphire Pressure	Microwave Proximity Probe	
Silicon-on-insulator Pressure	Fiber-optic Laser Vibration	
	Leak Isolation	
	Radioisotope Wear	
	Optical Pyrometer	
	Laser Blade Clearance	

Use Of Maintenance Sensors Will Improve Fault Detection And Reduce External Inspection Requirements

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SUBSYSTEM INSPECTION – PROPULSION
Advanced Maintenance Sensors
Avionics Enabled Savings

- Enables Inflight Detection Of Faults Which Cannot Be Easily Observed During Postflight Inspection.
  - Mission success related instrumentation does not cover all possible component failure modes.
  - Most instrumentation emphasizes flight critical components rather than high maintenance ones.
- Aids Isolation Of Failures To The Lowest Possible Level (i.e. LRU, module, Etc).
- Enables Inflight Fault Recognition So That Maintenance Requirements Are Determined Prior To Mission Completion.
  - Reduces unscheduled maintenance.
  - Uses maintenance downlinks,vehicle health management, advanced instrumentation.

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